Assessing the implementation efficacy of an Ecosystem Approach to Fisheries management in the South African sardine fishery

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Declaration

I know the meaning of plagiarism and declare that all of the work in this thesis, save for that which is properly acknowledged, is my own. This thesis has not been submitted in whole or in part for a degree at any other university.

Signed: ES MCGREGOR

Date: 25 May 2015

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"Ubuntu"

Those who are ready to join hands can overcome the greatest challenges

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Glossary

Applied research	**Research which answers questions that have direct applications in the world; solving a practical problem.**
Boundary	**A socially constructed point or limit that distinguishes one social system or group from another.**
Boundary institution	**An institution or organisation that supports boundary crossing by proving mediating functions across the boundary, and facilitates communication among stakeholders at the boundary.**
Boundary object	**A material object used to focus interaction and communication around a specific topic or issue.**
Decision support system	**A computer-based system designed to support decision making processes by compiling relevant information from multiple sources.**
Department of Agriculture, Forestry and Fisheries	**One of the departments of the South African government. This department is responsible in overseeing and supporting the agricultural, forestry and fisheries sectors and ensuring access to sufficient, safe and nutritious food by the country's population.**
Department of Environmental Affairs	**One of the departments of the South African government. This department is responsible for protecting, conserving and improving the South African environment and natural resources.**
Ecosystem Approach to Fisheries	**Offers a more holistic approach to managing fisheries than traditional target resources-orientated fisheries management approaches. An Ecosystem Approach to Fisheries "strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties of biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries" (FAO, 2003:14)**
Expert	**Someone whose special knowledge or skills causes him or her to be considered an authority or specialist in that field.**
Expert system	**A class of computer-based decision support tool that can function as a framework to facilitate communication between the user, the knowledge base and the inference engine. Often used interchangeably with knowledge-based system.**
Interdisciplinary	**Research approach which draws from two or more different disciplines to work towards a common goal. Interdisciplinary research supports the synthesis of disciplinary frameworks.**
Knowledge-based system	**See Expert system**

Knowledge-based tool	**A conceptual model which can take explicit account of multiple objectives and various knowledge sources, including expert knowledge, to aid decision-making proceses.**
Mediated modelling	**The process of including stakeholders directly into the modelling process.**
Multiple criteria decision analysis	**An umbrella term describing a collection of formal approaches which take explicit account of multiple criteria to aid decision-making processes.**
Operational Management Procedure	**A scientifically evaluated process which pre-selects the types of data required to determine the levels of control measures, in this case the Total Allowable Catch, to be detailed in a fishery. Simulation testing is done to t involves an evaluation of the implications, for both the resource and the industry using the resource, of alternative combinations of monitoring data, analytical procedures, and decision rules to provide advice on management measures that are robust to inherent uncertainties in all inputs and assumptions used (Cooke, 1999). The simulation-test**
Participatory modelling	**See mediated modelling.**
Rapid prototyping:	**Rapid development of prototype models. Provides a means for building simple conceptual models while adding complexity as needed to address specific decision problems.**
Scientific Working Groups	**A body within the Branch Fisheries of DAFF which is tasked with formulating scientific advice. The main objective of these groups is to provide the best possible scientific advice regarding all scientific inputs into fisheries management, provide a forum for scientific debate and advice on research programmes with the Branch Fisheries. SWGs include the pelagic SWG which contributes advice for managing the small pelagic fishery and the EAF-SWG which addresses scientific advice for an EAF for all fisheries.**
Social learning	**Social learning is defined as the "collective action and reflection that occurs among individuals and groups as they work to improve the management of human and environmental interrelations" (Keen et al., 2005:4).**
Stakeholder	**A person, or group of people that have a stake in, or are affected by a particular issue or problem.**
Target resources-orientated management	**Refers to more traditional fisheries management approaches which primarily focus on fishing and the target resource.**

Transdisciplinary	**A research approach which draws from different disciplines to work towards a common goal. Transdisciplinary research moves beyond discipline-specific approaches, bypassing disciplinary frameworks to focus on the problem issue. Participation is extended beyond academia and research**
Wicked problem	**A problem that is characterised by being complex and persistent, difficult to define and delineate from bigger problems, with no right or wrong solution and often highly context specific. Examples of wicked problems include Ecosystem Approach to Fisheries management, climate change and the HIV/AIDS epidemic.**

List of acronyms

ADU	Animal Demography Unit
BCLME	Benguela Current Large Marine Ecosystem
BEP	Benguela Ecology Programme
DAFF	Department of Agriculture Forestry and Fisheries
DEA	Department of Environmental Affairs
EAF	Ecosystem Approach to Fisheries management
EAF-SWG	EAF Scientific working group
EoCA	East of Cape Agulhas
ERA	Ecological Risk Assessment
FAO	Food and Agriculture Organisation
MA-RE	UCT Marine Research Institute
MARAM	UCT Marine Resource Assessment and Management group
MCDA	Multiple criteria decision analysis
MSC	Marine Stewardship Council
OMP	Operational Management Procedure
RFA	Responsible Fisheries Alliance
SARChI ME&F	South African Research Chair Initiative in Marine Ecology and Fisheries
SWG	Scientific working group
SWG-PEL	Pelagic scientific working group
TROM	Target resources-oriented management
UCT	University of Cape Town
WoCA	West of Cape Agulhas
WWF	World Wildlife Fund

Abstract

Evaluating the implementation efficacy of an Ecosystem Approach to Fisheries in the South African sardine fishery

Emily Skye McGregor

An Ecosystem Approach to Fisheries management (EAF) offers a holistic approach for sustainable fisheries management by extending the traditional target resources-orientated management (TROM) to include wider social-ecological dimensions of fisheries. An EAF requires balancing of multiple, often conflicting objectives, effectively dealing with complexity and uncertainty, and engaging with diverse groups of stakeholders. Various tools within the field of Multi-criteria Decision Analysis provide a formal approach which takes explicit account of multiple criteria, while effectively dealing with risk and uncertainty. A knowledge-based tool was developed in this thesis to assess the efficacy of EAF implementation for the ecological well-being dimension in the South Africa sardine fishery. An iterative, participatory approach was adopted for its implementation. The modelling philosophy applied a rapid prototyping approach, and an applied research perspective was employed to direct the research. A broad group of stakeholders participated in indicator selection, tool design, and interpretation.

The knowledge-based tool provided a hierarchical framework for seven specific management objectives to which eleven ecological indicators were linked. Time series (1987-2009) were collated for each indicator, and a utility approach was used to transform indicators to a common scale. Weights for indicators and objectives were agreed to by stakeholders and combined through the objectives' hierarchy using weighted means. The resulting outputs were discussed in detail during focus group meetings to ensure that the tool was clearly presented and as intended helped improve the stakeholder's understanding of the process. It was confirmed that the

knowledge-based tool presents a transparent, repeatable and scientifically defensible approach, suitable to meet management requirements. The tool development process was useful in bringing diverse stakeholder groups together, and through applying the tool as a boundary object, has helped to bridge the boundary between the TROM and EAF research communities. Encouraging stakeholder interaction offers opportunities for social learning, which if carefully facilitated through the tool development process is likely to enhance the outcomes of this process and support more generally in bridging boundaries to EAF implementation. The combined focus on tool development and social processes supports effective implementation of an EAF in the South African small pelagic fishery and provide a model for other fisheries.

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Chapter 1

Introduction

1.1. An Ecosystem Approach to Fisheries management

It is widely recognised that an Ecosystem Approach to Fisheries management (EAF) presents a more inclusive and sustainable approach to fisheries management than the more traditional target resources-orientated management (TROM) approaches. Following the principles of sustainable development, an EAF requires broadening of the scope of traditional management to include ecological, social and governance issues (FAO, 2003). An EAF thus *"strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties of biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries"* (FAO, 2003:14) and emphasises the importance of stakeholder involvement in the management process (FAO, 2003, Garcia, et al., 2003, Degnbol, 2003 and Wilson et al., 2006).

A number of binding international agreements containing aspects of an EAF have been adopted over the past few decades. These include the 1971 RAMSAR Convention on Wetlands, the 1973 CITES Convention on International Trade in Endangered Species, the 1979 Bonn Convention on Migratory Species of Wild Animals, the 1982 Law of the Sea Convention, the 1992 Convention on Biological Diversity and the 1995 Straddling Fish Stocks Agreement (Garcia and Cochrane, 2005). The 1995 FAO Code of Conduct for Responsible Fisheries provided the first reference framework for an EAF, consolidating the principles and goals of numerous international conservation and sustainable development agreements (Garcia et al., 2003, Garcia and Cochrane, 2005). An EAF was formally recognised as a goal for fisheries management in 2001 by the Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem. This was reinforced at the World Summit on Sustainable Development in Johannesburg in 2002 where the Plan of Implementation required the signatory nations to "*develop and facilitate the use of diverse approaches and tools, including the ecosystem approach, the elimination of* *destructive fishing practices, the establishment of marine protected areas consistent with international law and based on scientific information, including representative networks by 2012*" (WSSD, 2002:18). The FAO Technical Guidelines for Responsible Fisheries were published in 2003 to provide signatory nations with guidelines for supporting EAF implementation.

Subsequently, there has been a definitive move towards implementing EAF in fisheries worldwide. Scientific baselines for EAF have been developed and a large quantity of scientific research has been carried out to better understand the complexity of marine ecosystems and fisheries (Hofmann et al., 2010, Jennings et al., 2014, Link and Browman, 2014). However, practical implementation of EAF has been difficult to achieve. Fishery managers are left grappling with understanding the complexities of EAF and finding effective means to identify and prioritise the multiple, often conflicting, objectives of an EAF (Paterson and Petersen, 2010, Jennings et al., 2014). Along with balancing multiple sources of knowledge, and evaluating risks and uncertainties, this information needs to be combined into a logical framework that can assessed in a transparent, defensible and repeatable manner (Jarre et al., 2008).

The FAO recommend a series of steps for developing an EAF management plan, which are outlined in Figure 1.1 below (FAO, 2003, Garcia and Cochrane, 2005). The principles of EAF need to be translated into national and policy goals to which priority issues can be operationalised. This is often achieved through the development of objectives that can be linked to management actions. Without the 'translation' of EAF from policy to management, it is unlikely that sustainable fisheries management will be achieved. The iterative nature of an EAF is highlighted in this process by feedback loops for revising objectives and indicators after monitoring, review and performance evaluation. Additional guidelines for EAF implementation have been developed, including the Ecological Risk Assessments applied in commercial fisheries in Australia and South Africa (Fletcher et al., 2002, Nel et al., 2007).

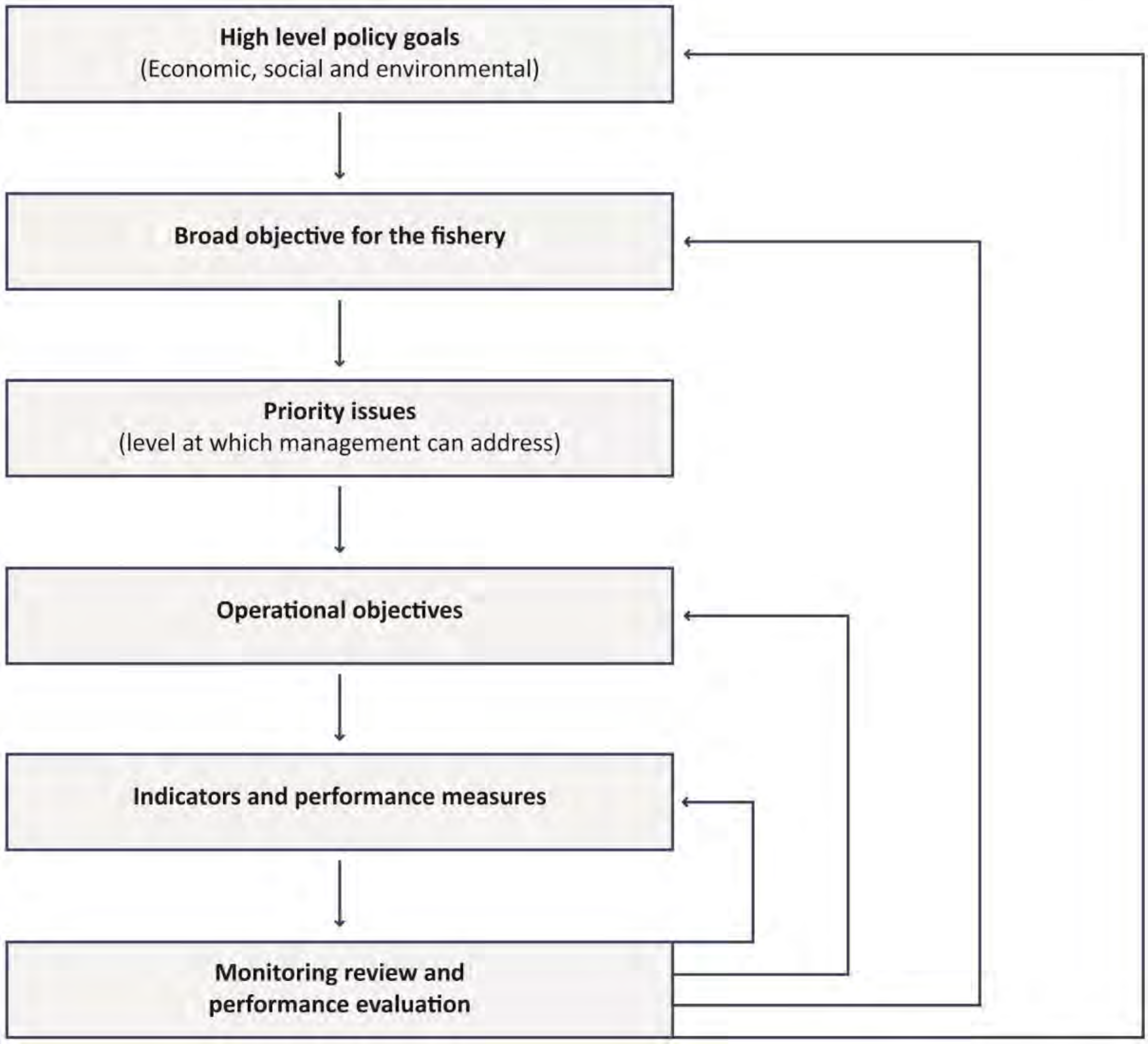


Figure 1.1: The iterative implementation process for EAF suggested by the FAO (2003).

A hierarchical framework has been developed to identify operational or management objectives relating to EAF (FAO, 2003). This framework, shown in Figure 1.2, divides EAF into three inter-related dimensions: Ecological well-being, human well-being and ability-to-achieve. The hierarchical structure helps to link objectives at different levels to high-level goals for sustainable development and allows for multiple, diverse and sometimes conflicting issues to be identified (FAO, 2003). While it is recognised that the social, ecological and governance dimensions of EAF are tightly coupled (Berkes and Folke, 1998, Ommer et al., 2011), to effectively implement an EAF, decision-makers need to balance multiple objectives and consider priorities and trade-offs between conflicting objectives.

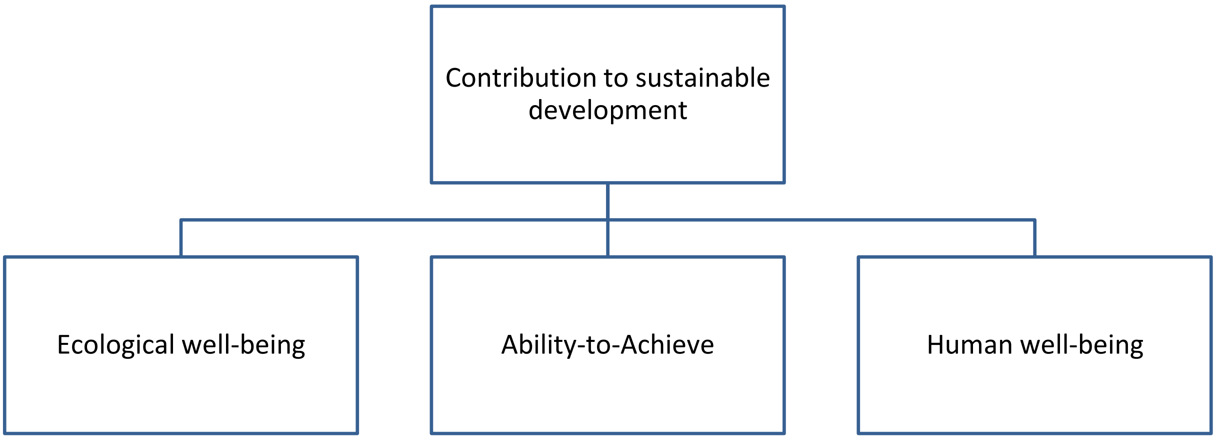


Figure 1.2: Conceptual framework of the three dimensions of EAF (adapted from FAO, 2003).

Addressing trade-offs and balancing multiple objectives is therefore an essential component of effectively implementing an EAF (FAO, 1999, Garcia and Staples, 2000, Degnbol and Jarre, 2004, Garcia and Cochrane, 2005). This often requires integrating several different criteria to support decision-making. Indicators are considered an important tool for EAF implementation (Garcia et al., 2000), and are used to translate ecosystem components and changes into management measures for decision-making (Garcia et al., 2000, FAO, 2003, Rice, 2003, Jennings, 2005). Indicators are thus an effective tool for linking the operational objectives of EAF to management action for effective EAF implementation (Garcia et al., 2000, Rochet and Trenkel, 2003, Rice, 2003, Jennings, 2005). However, as a result of the complexity of EAF, no single indicator can perform this function. Instead, a suite of indicators are needed, and often more than one indicator is required for a single objective (Shin et al., 2010). To make sense of indicators in decision-making, indicators should to be incorporated into broader approaches or frameworks (FAO, 1999). Indicator frameworks provide a synthesis and communication function in supporting decision-making around EAF.

1.2. Implementing an Ecosystem Approach to Fisheries management in the South African sardine fishery

South Africa, as signatory to the World Summit on Sustainable Development, has committed to implementing an EAF. To meet this goal, South Africa has adopted an incremental and proactive approach to implementing an EAF, considering EAF as a complementary approach to TROM approaches which aims to incorporate ecosystem considerations in decision-making rather than overhauling the management system. It is not intended to replace TROM (Shannon et al., 2010). However, the ecological approach is not a new concept in the management of human activities in the oceans around southern Africa (Hara et al., 2014). An extensive knowledge base for the ecological well-being dimension of EAF has been developed regionally through the Benguela Ecology Programme (BEP) and the Benguela Current Large Marine Ecosystem Programme (BCLME) (see Moloney et al., 2004, Hampton and Sweijd, 2008, O'Toole, 2008 for overviews) and in the southern Benguela ecosystem comprehensive reviews of the scientific knowledge base have been prepared by Shannon et al. (2004, 2006, 2010). More recently, progress has been made in creating a knowledge-base for the human well-being and ability-to-achieve dimensions of EAF in South Africa (see Hjort, 2008, Cochrane et al., 2009, Paterson et al., 2010, Sowman et al., 2013, Augustyn et al., 2014, Norton, 2014). While these provide a strong baseline for EAF in the southern Benguela ecosystem, fisheries managers are still grappling with the problem of how to effectively implement an EAF (Cochrane et al., 2009, Staples, 2010, Augustyn et al., 2014).

The objectives and principles of South African fisheries legislation and policies, in particular the Marine Living Resources Act No. 18 of 1998, relate closely to those of an EAF. Principles of an EAF contained within the Act include; the need for a holistic view of ecosystem conservation, the sustainable conservation of marine resources, the preservation of marine biodiversity, the application of the precautionary principle, and the need to balance sustainable ecological management with the governmental goals of economic growth, human resource development, capacity building and job creation. It also emphasises the importance of stakeholder participation in the decision-making processes. Numerous other environmental, marine and coastal legislation in South Africa incorporates either direct references to an EAF or includes principles of EAF (see Staples (2010) for a comprehensive list of relevant legislation). Regional agreements through the Benguela Current Commission further support the implementation of an EAF in South African fisheries (Staples, 2010, Augustyn et al., 2014).

The primary responsibility for managing fisheries in South Africa lies with the national fisheries department. Prior to 2010 this was Marine and Coastal Management (MCM) within the Department of Environmental Affairs and Tourism. MCM was responsible for fisheries management as well as all coastal zone and marine environmental management. However, in 2010 a cabinet reshuffle resulted in the dissolution of MCM and the separation of fisheries from environmental management. As a result of these changes the Branch Fisheries within the Department of Agriculture, Forestry and Fisheries (DAFF) was formed (South African Government Proclamation 44 of 1 July 2009). Fisheries research, monitoring and generation of management advice for decision-making are developed within the Fisheries Branch, and each fishery sector has both a Scientific Working Group (SWG) and Resource Management Working Group which help assess the status of resources and manage the fishery respectively. An EAF Scientific Working Group (EAF-SWG) was set up as a DAFF advisory group to address EAF issues at the national level. The EAF-SWG was instituted as a multiple stakeholder scientific forum, drawing expertise and interested parties together from the government (DEA and DAFF), universities, fishing industry representatives, conservation NGOs, and civil society groups to generate research and scientific advice towards implementing an EAF in South African fisheries. Progress has been made in advancing EAF implementation in a number of important commercial fisheries, including the demersal trawl fishery for hakes (for example, Maree et al., 2014) and the small pelagic fishery for sardine and anchovy (for example, Cherry, 2014).

EAF objectives are considered when generating scientific advice within the Pelagic Scientific Working Group (SWG-PEL) (for example, de Moor and Coetzee, 2012, Moseley et al., 2012, Coetzee, 2013), but fisheries management in South Africa is still heavily reliant on single or dual species stock assessments (Shannon et al., 2010). International reviews of the South African small pelagic fishery management have recommended that more ecosystem indicators be incorporated into fishery management approaches (Smith et al., 2011b, 2013). However, limited research capacity and funding within DAFF constrain the Fisheries Branch's ability to more effectively address EAF objectives (Augustyn et al., 2014). External organisations, in particular the Responsible Fisheries Alliance (RFA; www.rfalliance.org.za), CapeNature, WWF South Africa, BirdLife South Africa, the University of Cape Town's Marine Research Institute (Ma-Re), and Rhodes University have stepped in to address this gap and support EAF implementation.

The RFA is a partnership between WWF South Africa, BirdLife South Africa, and four major fishing companies in South Africa (Oceana, I&J, Sea Harvest and Viking) aims to enhance EAF implementation in South Africa and has made significant progress. Focussing on responsible and sustainable fisheries practices, the RFA facilitates EAF training for skippers, works with researchers and the private sector to better understand fishing impacts on seabirds and other predators, and facilitates market access through programmes such as the South African Sustainable Seafood Initiative (www.wwfsassi.co.za) and the Marine Stewardship Council.

The small pelagic fishery was the first fishery in South Africa to be targeted for EAF implementation (Nel et al., 2007). The ecological value of small pelagic species in the ecosystem, the commercial value of this fishery in South Africa, and the extensive knowledge base underpinning this fishery has helped progress in implementing an EAF (Moloney et al., 2004).

To track EAF implementation, a method to follow progress towards this goal was needed. The Ecological Risk Assessment (ERA) process (Fletcher et al., 2002, Nel et al., 2007) provided a means to start identifying issues and objectives relating to EAF that are not adequately addressed in management strategies in a number of key fisheries in South Africa, Namibia, and Angola, which together form the Benguela Current Commission (BCC; www.benguelacc.org). The ERAs provided a way to identify and prioritise the key issues relating to the three dimensions of EAF in each fishery, develop a suite of objectives and link these to potential management actions (Nel et al., 2007). The subsequent periodic ERA review workshops have developed a structured framework for tracking progress towards meeting the objectives of EAF identified during the ERA and provide a way to identify steps for assessing progress towards meeting these objectives (Paterson and Petersen, 2010). These processes have emphasised stakeholder participation and included consultation and discussion among a wide group of stakeholders (Nel et al., 2007, Paterson and Petersen, 2010, Smith and Johnson, 2012).

The ERA and ERA reviews provide a progress report towards meeting objectives for EAF and allow for a degree of comparison of progress in EAF implementation across fisheries (Paterson and Petersen, 2010). These frameworks, however, are limited in presenting progress in EAF implementation on the ground and rely on descriptive response and process indicators of progress. A different approach is required to track the efficacy of EAF implementation on the ground.

Jarre et al. (2006) proposed in their paper on predicting long-term ecosystem changes in the southern Benguela a suite of indicators to track EAF implementation. These authors identified the need for formal mechanisms to combine the signals of various indicators in support of management in the region. Expert systems, or knowledge-based systems, are one such framework. Expert systems are a form of multi-criteria decision support tools which offer a structured way to assess multiple criteria and incorporate multiple knowledge sources to aid decision-making by mimicking the way experts make decisions. Based on this suggestion by Jarre et al. (2006), Paterson et al. (2007) developed the first prototype of an electronic expert system to track the implementation efficacy of EAF in the South African sardine fishery. This expert system developed a way to synthesise indicators of the three dimensions of EAF in order to provide a holistic view of EAF implementation to support of decision-making in this fishery. Following the hierarchical framework presented by the FAO (2003) (see Figure 1.2) and linking the objectives identified in the ERA to the three dimensions of EAF, Paterson et al. (2007) identified a suite of indicators to measure the efficacy of meeting the objectives for EAF implementation. This first prototype was developed with a small group of stakeholders.

Paterson et al. (2007) demonstrated that structuring a complex problem in such a manner was useful in improving stakeholders' understanding of the extent of issues related to an EAF and improved communication among the stakeholders. However, the authors focused on enhancing understanding amongst the stakeholders over the precision of the model (Paterson et al., 2007). By doing so, there was limited reliable data input into the expert system and while stakeholder engagement was sufficient for this prototype wider involvement of stakeholders was needed to improve uptake of this system within the government department. In addition, much need revisions to the objectives underlying the model were required. Further research on human well-being indicators was carried out (Paterson et al., 2010). The ecological well-being dimension of this expert system still required refinement. To do this requires the improvement of the indicators and the model structure of the expert system. This is possible given the strong scientific base in the ecological well-being dimension for the South African sardine fishery. The EAF-SWG has recognised the value of the expert system in supporting strategic management advice for EAF implementation and has recommended that further research be done to include an updated suite of indicators in support of EAF in the sardine fishery (EAF-SWG, 2007).

1.3. Thesis aim and structure

This thesis aims to develop, to completion, a full prototype knowledge-based tool (a variation of Paterson et al.'s (2007) expert system) to track the implementation efficacy of the ecological well-being dimension of EAF in the South African sardine fishery.

The knowledge-based tool will introduce a transparent, repeatable and scientifically defensible methodology for evaluating a suite of indicators against objectives of ecological well-being in the sardine fishery. The aim of this tool is to provide a synthesis of objectives for ecological well-being in the sardine fishery that can be useful in understanding trade-offs and priorities for EAF implementation as well as being potentially useful tool to enhance communication among stakeholders around these issues. This thesis aims to draw on an interdisciplinary perspective, drawing methodology from different disciplines, to guide both the development of a scientifically-robust a tool to track EAF implementation while maintaining focus on the participatory process of tool development with stakeholders.

It is envisioned that the knowledge-based tool could be used by stakeholders and decision-makers as a strategic planning tool to track the implementation of EAF in the fishery, communicate the complexity, trade-offs and uncertainties relating to implementing an EAF and guide thinking around the issues of EAF in the fishery among stakeholders.

The process adopted through this thesis is presented in Figure 1.3, which provides a conceptual framework of how each chapter in this thesis addresses an aspect of the research process. The process is highlighted in this figure through the iterative process of knowledge-based tool development. Feedback loops as displayed by the arrows allow for iterations between the steps as well as through the entire process. The key results and process steps in each chapter of this thesis are detailed below.

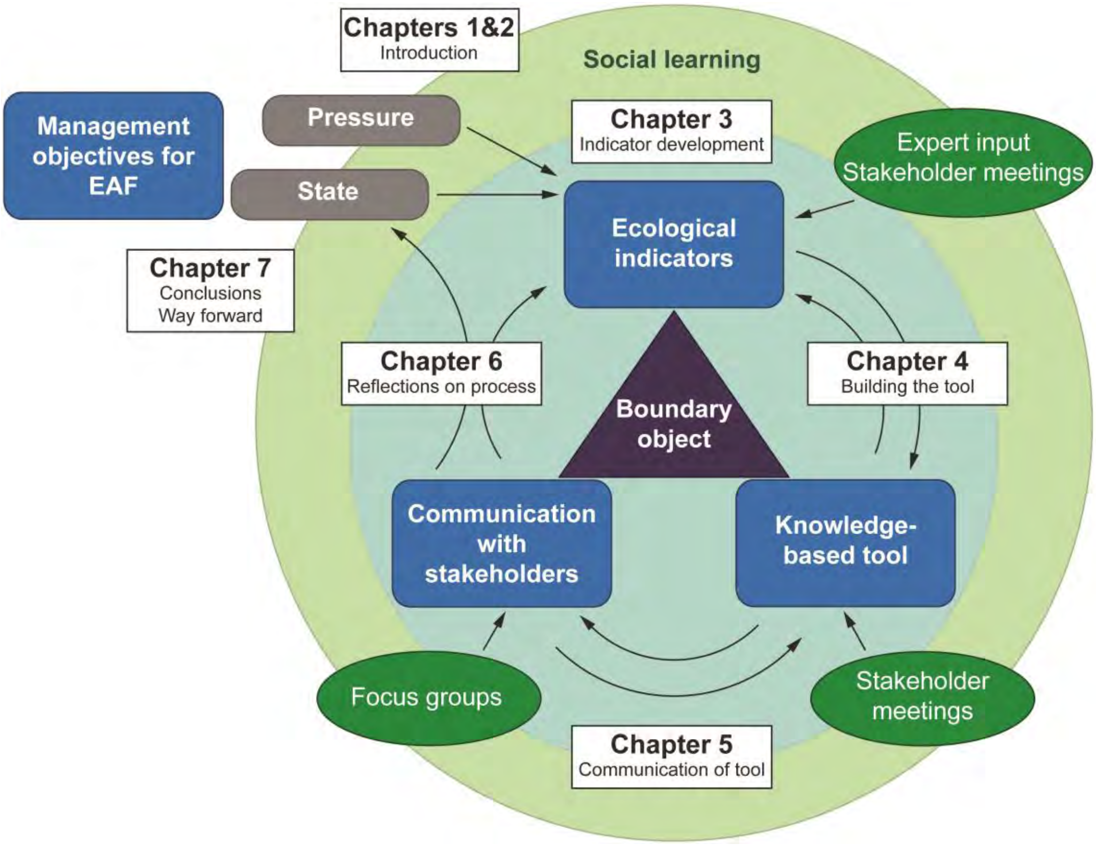


Figure 1.3: The conceptual framework for evaluating the implementation efficacy of an EAF in the South African sardine fishery through knowledge-based tool development. This framework represents an iterative process incorporating the structure of this PhD thesis.

Chapters 1 and 2 provide an overview of this thesis' aims and provides a review of key literature while placing this research in context of South African fisheries management and EAF implementation. A suite of indicators matched to pressure and state objectives (OECD, 1995) for the ecological well-being of EAF in the sardine fishery are developed in Chapter 3. It is important that the indictors represent the best available scientific data and expert knowledge. All efforts were made to ensure the process of indicator identification and development is transparent and scientifically defensible and that stakeholders were consulted at appropriate times during this process. Chapter 4 presents the development of the new prototype knowledge-based tool. Stakeholder meetings helped to identify an appropriate method for aggregating indicators and objectives structured through an objectives' hierarchy. A thorough sensitivity analysis on the tool structure and outcomes was conducted to ensure an appropriate modelling process.

Chapter 5 details the approach taken in improving the visualisation and presentation of the knowledge-based tool for communication among stakeholders. As the knowledge-based tool only becomes useful when applied, further focus on designing a tool that would be useful to the stakeholders was needed. A series of focus groups were held with stakeholders, the results of these meetings are detailed in Chapter 5. Chapter 6 draws on the social theories of boundary crossing and social learning to reflect on the iterative process of developing the knowledge-based tool for use in implementing EAF in the sardine fishery. Chapter 7 draws together the key findings and conclusions and maps a way forward for a new prototype of this facilitated, iterative process.

Chapter 2

Literature review and thesis background

This chapter provides the relevant context and literature review to address the various components of this thesis. It starts with outlining the importance of forage fish in the southern Benguela ecosystem, which is followed by a detailed description of the South African small pelagic fishery and the current management structure of this fishery. A short discussion of literature on fisheries and complexity provides context for understanding the value of an ecosystems approach in fisheries management and the need for methods to balance multiple objectives when managing fisheries. This is followed by an introduction to key literature and research progress in multi-criteria decision analysis and stakeholder participation in fisheries management. The chapter concludes by considering literature on boundary crossing and social learning in natural resource management.

2.1. The role of forage fish in the southern Benguela ecosystem

The southern Benguela is an upwelling system off the coast of South Africa. This highly productive ecosystem supports large biomasses of small pelagic, or forage fish, including sardine (*Sardinops sagax*), anchovy (*Engraulis encrasicolous*), redeye round herring (*Etrumeus whiteheadi*), and mesopelagic species. Small pelagic species play an important role in regulating ecosystem functioning. They occupy a mid-level position in the food web, and therefore influence the abundance of both the plankton which they feed on, and the top predators, such as the fish, seabirds and large marine mammals which feed on them (Cury et al., 2000). Sardine and anchovy are a planktivorous, highly fecund, short-lived, and highly mobile species (van der Lingen et al., 2002). These characteristics make them sensitive to environmental changes and inter-annual and decadal-scale variability in abundance, distribution, and recruitment (Cury et al., 2000, van der Lingen et al., 2002).

Small pelagic species tend to experience ‘boom and bust’ periods in relative population biomass (van der Lingen et al., 2002). The South African sardine fishery has experienced substantial fluctuations in population size over the past 60 years. Recovering from a collapse in the population following large population numbers in the 1950s, sardine were found in low abundance during the 1960s. This was followed by a subsequent recovery of the population by the 1980s, with population sizes by the mid-2000s reaching similar or larger quantities to that observed in the 1950s (van der Lingen et al., 2006). 'Regime shifts', or species dominance shifts, have been observed in the relative biomass of sardine and anchovy in the southern Benguela, experiencing alternating species dominance on a decadal scale (Cury and Shannon, 2004, van der Lingen et al., 2006).

Recent spatial shifts in the distribution of sardine and anchovy, from being predominately situated on the west coast (the area west of Cape Agulhas) to being situated on the south coast (east of Cape Agulhas) have been observed. A gradual increase in the relative biomass of sardine located east of Cape Agulhas has been observed from 1997-2005, followed by a recent reversal from 2008 (Figure 2.1). A similar shift has been observed for anchovy (Roy et al., 2007). This spatial change in species distribution has been attributed to both the effects of localised overfishing (sardine) and changes in the environment (anchovy) (Coetzee et al., 2008a). Roy et al. (2007) hypothesized that the eastward shift in distribution of anchovy across the Agulhas Bank since 1996 could be attributed to changes in environmental forcing in the region, which resulted in a better feeding environment in the area east of Cape Agulhas (Howard et al., 2007, Blamey et al., 2012). Coetzee et al. (2008b) could not assign an environmental driver to the shift eastwards in sardine biomass experienced since 2001. Both Roy et al. (2007) and Coetzee et al. (2008b) explored the implication of localized overfishing on the west coast of South Africa as a driver of the distributional shift of sardine to the east of Cape Agulhas. A recent PhD thesis (Watermeyer, in prep) uses spatial indicators to explore possible ecosystem implications of species distributional shifts along the Agulhas Bank, confirming changes at the ecosystem scale and the role that fisheries could have in driving such changes.

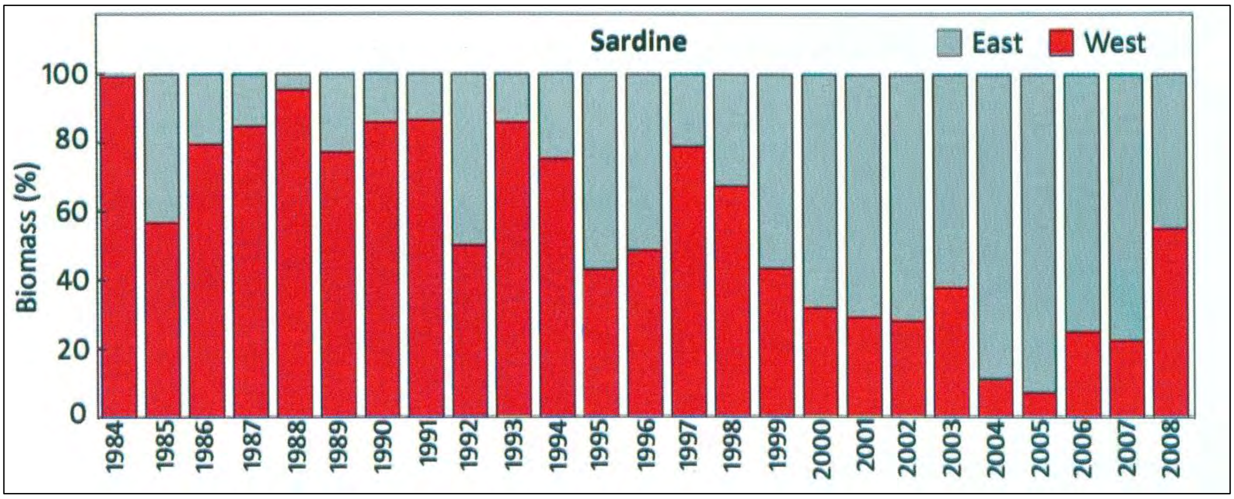


Figure 2.1: The percentage of the total sardine biomass located to the east and west of Cape Agulhas observed during surveys conducted annually between late October and early December 1987-2008. Note the gradual increase in the proportion of sardine situated east of Cape Aghulas from 1997 to 2005 and a reversal from 2008 (adapted from van der Lingen et al., 2011) [Colours edited from the original with permission from the author].

The spatial shift in small pelagic fish biomass has provided an interesting challenge in managing this fishery, with concerns being raised over the effect of localized overfishing on the west coast. Minimising the risk of spatially disproportionate fishing has become an increasingly important issue in managing the small pelagic fishery (Nel et al., 2007). Changes in small pelagic fish abundance and distribution can have serious consequences for dependent top predators, in particular endemic seabirds (Crawford et al., 2008, Cury et al., 2011). Hutchings et al. (2012) present an overview of the history of the dynamics of top predators in the southern Benguela, and the relationship between forage fish abundance and seabird population health is discussed in detail in Chapter 3.

2.2. South African small pelagic fishery

The commercial, pelagic purse seine fishery is South Africa's largest fishery by volume and, after the demersal trawl fishery, the second most valuable (Shannon et al., 2006). In operation since the late 1940s, this fishery targets primarily sardine and anchovy, with smaller landings of redeye round herring, juvenile horse mackerel (*Trachurus capensis*) and mesopelagic lanternfish (Myctophidae, *Lampanyctodes hectoris*). The small pelagic species distribution extends from southern Namibia to Richards Bay on the northeast coast of South Africa (Figure 2.2; Beckley and van der Lingen, 1999, Coetzee et al., 2008b). Fishing occurs inshore, predominantly along the Western Cape west and south coasts for sardine and anchovy and further along the Eastern Cape coast for sardine (Coetzee et al., 2008b). Anchovy, redeye, horse mackerel, and to a small degree lanternfish are reduced to fishmeal, fish oil, and fish paste. Sardine is canned or frozen for human consumption, pet food, and bait. Processing factories are situated primarily on the west coast, with a factory in Mossel Bay and one in Port Elizabeth.

The South African small pelagic fishery has been in operation since the 1940s, being predominately situated off the west coast. Intensive fishing continued during the 1950s, with catches exceeding 400 000t by the early 1960s. The high exploitation of this booming fishery and low sardine biomass in late 1960s resulted in unsustainable catches, and combined with low relative biomass of sardine over this period, and an eventual decline in fishery landings by the late 1960s (Figure 2.3). Continuing low catches averaging 80 000t were taken throughout the 1970s, declining even further to 40 000t by the mid-1980s. The implementation of regular fishery-independent acoustic surveys and a stock rebuilding strategy, which included the allocation of an annual Total Allowable Catch in the 1980s, resulted in the recovery of sardine stocks (Coetzee et al., 2008b). High recruitment and a peak in sardine biomass over the period 2001-2005 (Figure 2.4) resulted in catches averaging more than 200 000t that was followed by a sustained period of low sardine recruitment, and combined catches leveling off at 100 000t in 2006-2007 (Coetzee et al., 2008b).

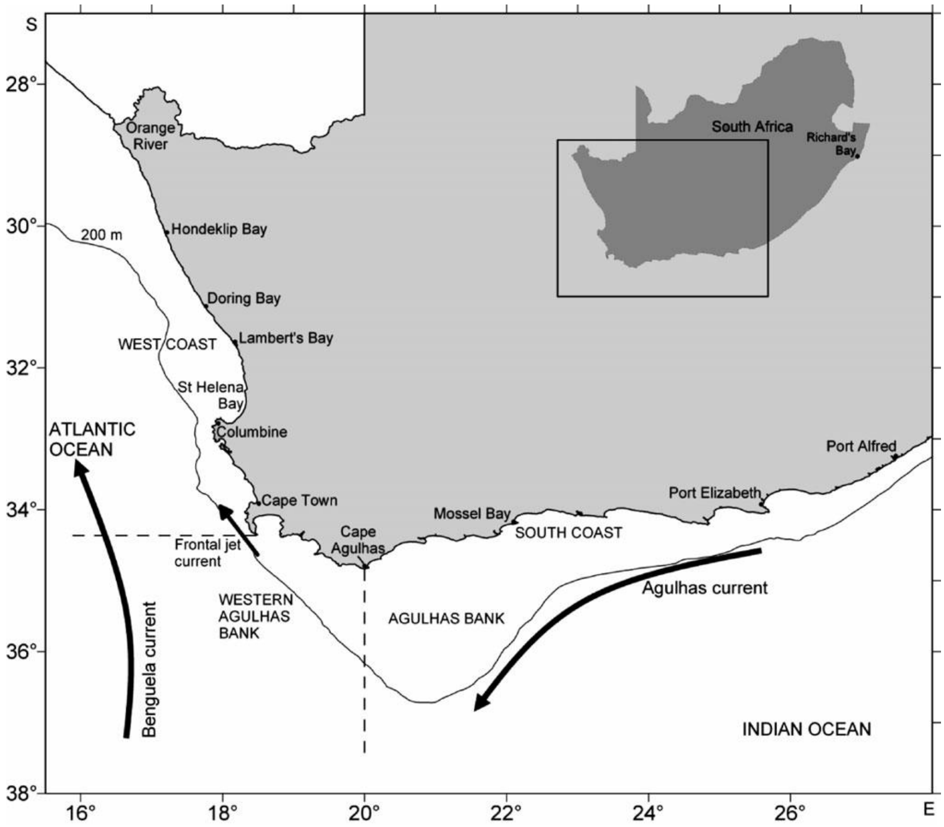


Figure 2.2: Map of the South African coastline (from Coetzee et al., 2008b). Small pelagic species are situated off the west and south coasts of the Western Cape. The small pelagic fishery extends to the east and west of Cape Agulhas on the Agulhas Bank, the sardine-directed fishery extends further up the coast to Port Alfred in the Eastern Cape.

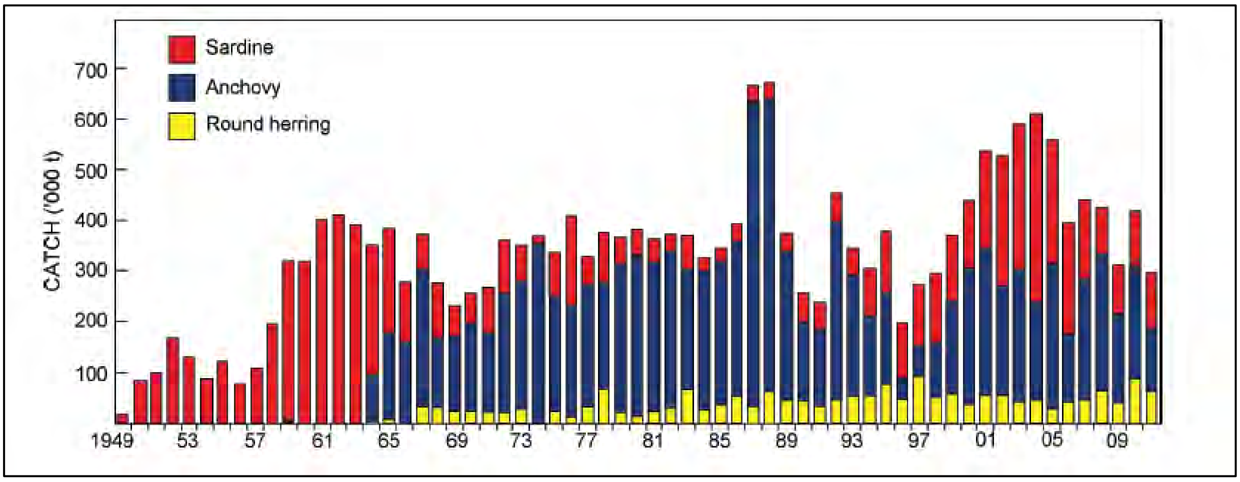


Figure 2.3: Annual catches of sardine, anchovy and round herring taken by the South African small pelagic fishery 1949-2011 (from van der Lingen et al., 2012).

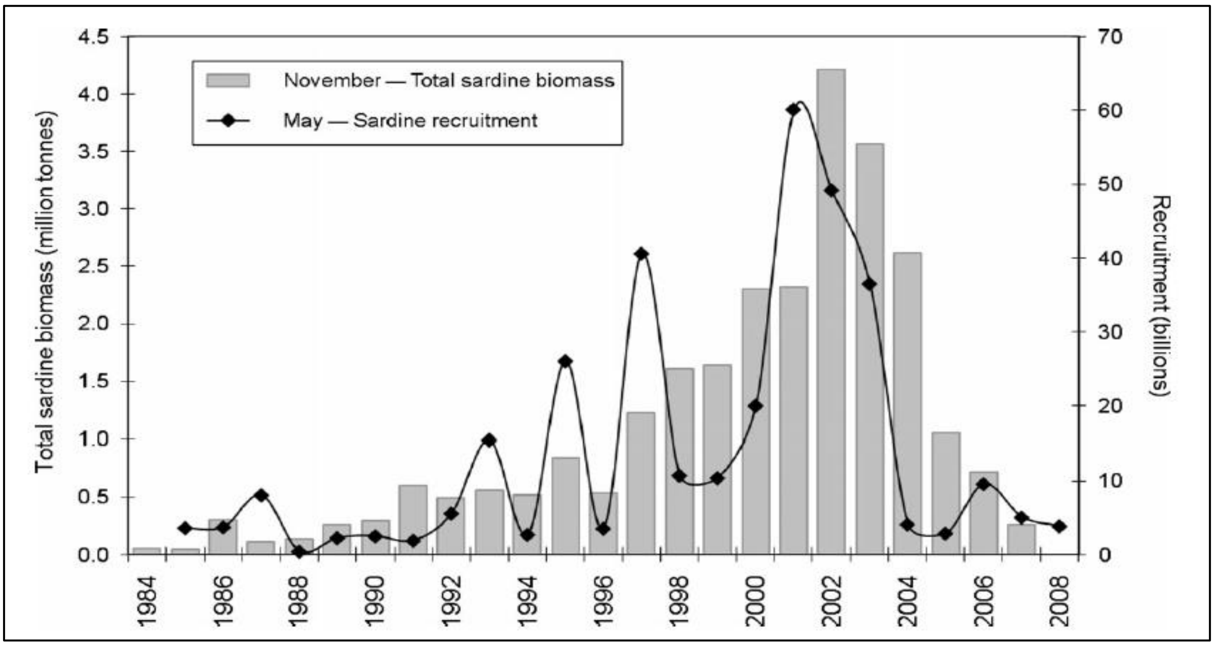


Figure 2.4: Annual sardine biomass observed during surveys conducted in November and sardine recruitment from May surveys (from Coetzee et al., 2008b).

The South African small pelagic fishery is currently managed through the Branch Fisheries, Department of Agriculture, Forestry and Fisheries (DAFF). The DAFF Pelagic Scientific Working Group (SWG-PEL) and Resource Management Working Group are responsible for the management of the small pelagic fishery (for details on management structure of the Branch Fisheries, see: http://www.daff.gov.za/daffweb3/Branches/Fisheries-Management/Fisheries-Research-and-Development).

The SWG-PEL is a scientific forum tasked with formulating sound scientific advice for decision-making. This group consists of scientists and technicians from within the Branch Fisheries with relevant expertise in management, biology and stock assessment and external scientists from universities and other institutionswith relevant knowledge. Representatives from the fishing industry and conservation NGOs are invited observers in the working group meetings. Tasks of this group include directing and setting research priorities, devising the Operational Management Procedures (OMP) that generate advice for Total Allowable Catch

(TAC) levels. The Resource Management Working Group is responsible, among other tasks, for final approval of TAC recommendations of which are sent through this group to the the DAFF Minister for final approval in setting the final annual TACs.

The small pelagic fishery is managed by effort limitations through access rights, vessel licensing, and bycatch limits. Seperate TACs for sardine and anchovy are set annually and fixed Precautionary Upper Catch Limits (PUCL) are set for redeye round herring and horse mackerel.

A joint OMP for sardine and anchvoy is used to set annual TACs in the small pelagic fishery. The OMP uses algorithms that base TAC levels on stock sizes estimated from observations during two annual monitoring surveys. An annual TAC is set for sardine and an initial and a final TAC are set for anchovy each year, the final TAC accounting for observed anchovy recruitment because the fishery for this specices is primarily recruit-based. Juvenile sardine and juvenile horse mackerel are caught as bycatch in the anchovy-directed fishery, an annual Total Allowable Bycatch (TAB) is set for juvenile sardine and a PUCLis used for horse mackerel.

OMP development is carried out by the UCT MARAM group on contact with DAFF and includes input from fishery scientists, industry representatives and other interested parties as part of the Pelagic Scientific Working Group (PEL-SWG). The objective of the OMP is to maximise sardine and anchovy catches in the medium term, while ensuring that the risk to either population does not exceed agreed levels. The OMP also includes constraints on the year-to-year variability of the TAC to ensure industry stability. Input data for the OMP include fishery-independent hydro-acoustic surveys and fishery-dependent data. An OMP cycle typically lasts for four years. Revisions or adaptations to the OMP are carried out after each cycle to include new and updated information and any new insights into the role of small pelagic fish in the ecosystem that may become avaliable.

Two hydro-acoustic surveys are conducted annually by DAFF. A summer November biomass survey measures the total stock sizes and an autumn May/June survey measures recruitment. These hydro-acoustic surveys have been conducted annually since 1984, with a spatial component added to the surveys in 1987 (Coetzee et al., 2008a). Other important data are collected during the survey trips, including biological parameters required for the OMP (for example, information underlying population age-structure)and other biological and ecological information (for example, temperature, salinities and oxygen). Continually improving technology and data analysis techniques over time have improved the quality of the acoustic time series and biomass estimates obtained during these surveys (Coetzee et al., 2008a, de Moor et al., 2011). The surveys have been lauded to produce some of the best quality and quantity of information in the world (Smith et al. 2012, van der Lingen et al., 2012).

Fisheries-dependent data are collected routinely, and include catch statistics (for example, landed mass, catch timing and position). Representative sampling of commercial fish catches are routinely conducted and include the size composition and biological characteristics of catches. Accurate reporting and reliable monitoring are required to ensure these data are precisely and consistently recorded.

EAF objectives are considered by the SWG-PEL when generating scientific advice (de Moor and Coetzee, 2012, Moseley et al., 2012, Coetzee, 2013). Ecosystem considerations currently addressed within the SWG-PEL include the penguin island closure experiment which aims to assess the localised impacts of fishing on the survival and breeding success of African penguin colonies (Weller et al., 2014, Dunn et al., 2014, Sherley et al., under review). Two models of African penguin dynamics have recently been developed, one in conjunction with the revisions to the OMP (Robinson, 2013) and the other using a systems modelling approach (Weller et al., 2014). In addition, investigations into changes in sardine and anchovy distribution and subsequent implications of spatially disproportionate fishing are ongoing within the SWG-PEL (for example, Coetzee et al., 2008b, de Moor and Butterworth, 2008, de Moor et al., 2014) and under the auspices of the EAF-SWG (for example, Shannon et al., 2014). Hypotheses around the possible existence of multiple sardine stocks in the southern Benguela are also currently being investigated (de Moor and Butterworth, 2009, van der Lingen et al., 2009, Reed et al., 2012, de Moor and Butterworth, 2013a, 2013b, Chiazzari, 2014, de Moor et al., 2014 and Hampton, 2014). OMP revisions to take into account stock structure and spatially disproportionate fishing are currently being developed (de Moor and Butterworth, 2013b, 2013c, Smith et al., 2013, 2014).

Further research into ecosystem-based management of the small pelagic and other fishery sectors at DAFF has been co-ordinated through the EAF Scientific Working Group (EAF-SWG). The EAF-SWG is a multiple stakeholder scientific forum drawing expertise and interested parties together from the government (Department of Environmental Affairs and DAFF), universities, fishing industry representatives, and conservation NGOs to generate research and scientific advice towards implementing an EAF in South African fisheries. Scientific and management advice that was generated in this group includes the methodological development of ecosystem indicators expert systems (for example, Shannon et al., 2014), penguin-related conservation management (for example, Weller et al., 2014), and phosphate mining on the Agulhas Bank (EAF-SWG, 2012).

Recently, and subsequent to the research presented in this thesis, the EAF-SWG has been dissolved. The dissolution of this group emphasises the need for other fora to drive EAF implementation, and this is discussed further in Chapter 6.

2.3. Fisheries and complexity

Fisheries and coastal environments are complex, adaptive social-ecological systems that are characterised by complex interactions at various scales (Berkes and Folke, 1998, Jentoft and Chuenpagdee, 2009, Ommer and Perry, 2011, Ommer et al., 2011, Berkes, 2012). The social and ecological components of these systems are seen as coupled and interdependent, nested within one another (Berkes and Folke, 1998, Ommer et al., 2012).

Drivers of change that affect social-ecological systems do so in complex and unpredictable ways (Berkes and Folke, 1998). The dynamics of fisheries span multiple scales, covering temporal, spatial and governance dimensions and involve multiple actors. The governance of fisheries is now widely considered a 'wicked' problem (Jentoft and Chuenpagdee, 2009, Khan and Neis, 2010). Wicked problems, in opposition to 'tame' problems, are characterised as being *"difficult to define and delineate from other and bigger problems"* and tend to have no right or wrong solution, no technical solutions and it is often unclear when they are solved, or if they ever can be solved (Jentoft and Chuenpagdee, 2009:553, after Rittel and Webber, 1973). Wicked problems are often so complex and persistent that people tend to disagree on how to define the problem, what causes it, and what it would take to provide a solution to the problem (Rittel and Webber, 1973). When solutions to wicked problems are found they are often highly contextual. Solutions may only work in a certain place at a certain time, and not in another context or at a different time. Khan and Neis (2010) suggest the exploring of solutions for fisheries problems through 'clumsy solutions'; which applies exploratory solutions which requires the input of diverse stakeholders, information sharing, knowledge synthesis, and trust building.

Understanding and framing the problem of fisheries governance as a wicked one provides an incentive for the development of more inclusive and holistic approaches for the management of fisheries (Ommer et al., 2007, Jentoft and Chuenpagdee, 2009, Khan and Neis, 2010). Based on these characteristics, Berkes (2012) suggests that Ecosystem-based Fisheries Management is a wicked problem. Other examples of wicked problems include; adapting to climate change, watershed management, the conservation of endangered species, and containing the HIV-AIDS pandemic.

Fisheries management has been moving away from managing fisheries as individual stocks and individual fishing fleets towards a broader, more inclusive approach, drawing on multiple stakeholders, disciplines, and objectives, envisioning fisheries as social-ecological systems (Cochrane and Garcia, 2009, Berkes, 2012, Ommer et al., 2012). This requires management structures to match the scales, complexity, and interdependencies of social-ecological systems (Ommer et al., 2012). Berkes (2012) critiques current approaches for implementing an EAF, which tend to complement and expand traditional management paradigms, suggesting that an evolutionary approach to implementing EAF is insufficient to effectively deal with the multiplicity of issues and complexity associated with fisheries, and that a more revolutionary approach should be considered.

Whether there is a revolution or the slower evolution of fisheries management towards an EAF, a paradigm shift is required. More strategic, broad scale approaches are needed in addition to the tactical, narrow-focused management approaches currently applied in South African fisheries management (Shannon et al., 2010). This will require new ways of thinking, interdisciplinary approaches, and respectful collaboration (Shannon et al., 2010). Stakeholder buy-in and participation will be required for effective implementation (Shannon et al., 2010).

This thesis is aims, through developing a knowledge-based tool to offer a transparent and repeatable methodology supporting strategic planning for implementing an EAF in the South African sardine fishery. Through this process, this thesis aims to contribute to making explicit the multiple objectives, simplifying the complexity and addressing trade-offs in achieving an EAF.

2.4. The application of multi-criteria decision analysis and expert systems in fisheries management

Decision problems in fisheries management are complex and are characterised by uncertainty in the knowledge base, as well as multiple and often conflicting objectives and diverse stakeholders (Belton and Stewart, 2002). Decision problems typically do not present themselves in a structured form, complete with lists of alternative courses of action and decision-making objectives ready for systematic analysis. Rather, they are a human construct, emerging as stakeholders struggle to gain a shared understanding of the situation at hand and strive towards a joint solution (Belton and Stewart, 2002). Various tools within Multi-Criteria Decision Analysis (MCDA) provide a formal approach which takes explicit account of multiple criteria, while effectively dealing with risk and uncertainty. This allows the combined evaluation to be transparent and understandable to all those involved in the decision-making process (Belton and Stewart, 2002, Paterson et al., 2007). This process may help to increase stakeholder buy-in, making the process transparent and the decision defensible, and provides a documented basis for possible modifications of the decision in the future (Belton and Stewart, 2002, Goodwin and Wright, 2004).

Jarre et al. (2011) provide a review of multi-criteria decision support tools used in the field of MCDA that have been applied in fisheries management in South Africa and Europe. These tools include problem structuring, scenario planning, expert systems and more ‘classical’ MCDA approaches such as preference modelling and outranking methods (Jarre et al., 2011). These approaches can help for the decision process to remain structured, transparent and documented and allow for group interactions where multiple groups of diverse stakeholders can be included in the process. Detailed descriptions of MCDA approaches and the application of these in statistical and management sciences are provided by Belton and Stewart (2002) and Goodwin and Wright (2004).

Expert systems, also known as knowledge-based systems, are type of computer-based decision support system that mimic the way decisions are reached by experts.

In this way, expert systems help to make the decision process transparent, defensible, communicable, and reproducible to a wider audience (Belton and Stewart, 2002, Goodwin and Wright, 2004). Expert systems are used in the field of decision science, being most useful in repetitive decision-making or advice-giving situations and can handle knowledge represented in many different ways and from a wide variety of sources, both qualitative and quantitative. Conventional approaches to assessing the adequacy of a system focus on the convergence between the system's decision (diagnosis or advice) and that of the group of experts whose knowledge is modelled in the system.

There are various ways to incorporate the knowledge base into an expert system. Often decisions in expert systems are modelled using IF-THEN rules. This method can provide freedom to a model in a given decision process, because no normative theory oversees the aggregation or selection of these rules into an optimal set or sequence for execution when the system is used. Fuzzy sets admit partial membership of a category, for example, not being black or white but 'grey'. This allows the incorporation of uncertainty in premises and in rules and fuzzy set theory provides methods to combine the uncertainty within and between rules (Zimmermann, 2001).

While acknowledging the flexibility of rule-based approaches, Stewart and Joubert (2006) caution against a loss of transparency through rule proliferation. However, the approach is still very valuable for small expert systems, comprising tens rather than hundreds of rules (for example, Starfield and Bleloch, 1991, Miller and Field, 2002). Jarre et al. (2008) highlight the potential of such small expert systems to summarise complex information and emphasise the ease with which rules, as natural language, are communicated among stakeholders.

Expert systems have various applications in the context of fisheries management, and the following section will briefly summarise some of these approaches. Gurocak et al. (1998) developed an expert system based on fuzzy set theory and IF-THEN-

ELSE rules to select project alternatives that aimed to increase the number of salmon in the Columbia River Basin in North America's Pacific Northwest in line with a recovery plan. The values of five input attributes (indicators) were transformed into fuzzy variables, representing relative membership to three categories; ‘low’, ‘medium’, and ‘high’ on a common scale (0 to 1), which were combined using decision rules. An example rule would read *"If genetic risk is low and harvestable fish is medium and natural escaped fish is medium and cost is low then utility is good*”. The authors designed an automatic procedure to replace the assignment of weights by decision makers which is usually required by classical MCDA methods. That expert system was compared with the results of a weighted summation method, and an interactive method, and the authors concluded that the expert system outperformed both methods (Gurocak et al., 1998). The application of this method is limited by the dependence of the system on the initial definition of the fuzzy transformation for each input.

Caddy (1999, 2006) described a framework for precautionary management suitable for use in fishery assessments in data-poor situations. He proposed a system of green, yellow and red (‘traffic’) lights to categorise multiple indicators relevant to the state of a fishery and ecosystem in relation to defined thresholds. Integral to this approach is a set of decision rules on management actions to be taken depending on the numbers of lights of each colour that are recorded, with the measures becoming more restrictive as the proportion of red lights increase. In application, the integrative function of the traffic light categories and the set of management response rules could make this an expert system. Halliday et al. (2001) elaborated this approach and suggested it as a method for integrated fisheries planning. These authors included a helpful template for the description of an indicator to be used in the system and explored ways of employing fuzzy set theory. The traffic light system has subsequently been applied in a number of fishery assessments, including shrimp stocks in the North Atlantic (Koeller et al., 2000), the snow crab fishery in the Gulf of St. Lawrence (Caddy et al., 2005), the broadtail shortfin in the central Mediterranean (Ceriola et al., 2007), and more regionally, the southern Angolan leerfish fishery (Potts et al., 2008).

Korrûbel et al. (1998) developed two rule-based deterministic models which use quantitative and semi-qualitative data to relate recruitment strength in the South African anchovy fishery to biological and physical indicators. That paper presented the first attempt at predicting anchovy recruitment success, which was beneficial for more effective management of the commercial anchovy recruit fishery in the southern Benguela ecosystem early in the fishing season. Miller and Field (2002) chose another approach to provide a qualitative estimation of anchovy recruitment strength using crisp classification trees and a rule-based expert system. Similar to the traffic light approach, they employed four categories of recruitment strength estimation. An illustrative run of this expert system is provided in Jarre et al. (2008), who also compared the rule-based application of crisp classification with a piecewise linear approach (Fuzzy 'AND') (Paterson et al., 2007) as used in simple fuzzy transformations and concluded that the piecewise linear approach does not necessarily perform better than the crisp categories; the choice of numerical representation is likely to remain case specific.

Rochet et al. (2005) developed a rule-based, probabilistic expert system to assess on-going changes in exploited fish communities off the French coast based on data from scientific monitoring surveys. The objective of that system was to evaluate the existence of fishing impacts on the fish community in question, and if fishing impacts exist, determine whether the impacts have been increasing, stabilising, or declining over time. At the population level, relevant indicator trends were compared with expected probabilities of combined trends in diagnostic tables under the null hypothesis that populations were stable and the indicator trends in question are independent. At the community level, a sequential procedure was applied. As an example, starting from a state where a community was impacted by fishing, the average length in the fish community is examined first. If it is decreasing, the community was assumed to be deteriorating and the procedure was stopped. If not, the trend in total biomass was examined in the same way, and so on until all relevant indicators were examined. Finally, the results at the population and community levels were combined using the rule that as soon as one level was found to be deteriorating, so was the system. Conversely, improvement at both levels was deemed necessary to conclude that the system was recovering. The authors suggested that scientists were the intended audience, in line with the advisory framework suggested by Trenkel et al. (2007) where the diagnosis of changes in indicators resides with scientists, not with managers or other stakeholders.

A rule-based expert system, designed to provide early warning of long-term ecosystem change in the southern Benguela upwelling system is outlined by Jarre et al. (2006). Another expert system comparing the ‘states’ of the southern Benguela ecosystem for different decades was developed by Osman (2010) and Shannon et al. (2014) building on an initial decision tree by Bundy et al. (2010). Three decision trees where developed to examine fisheries management in the southern Bengeula ecosystem at the community level (pelagic-caught fish and demersal-caught fish community decision trees) and the system level (ecosystem decision tree). While conservative in the trends presented, that expert system provided a robust and effective framework for fishery managers, the intended target audience, to access the synthesised information and the reasoning behind conclusions (Shannon et al., 2014).

Based on Jarre et al. (2006), Paterson et al. (2007) constructed a prototype expert system based on fuzzy set theory to evaluate the implementation of an EAF in the South African sardine fishery. That system designed a hierarchy of increasingly specific objectives, and linked indicators to the most specific objectives. The indicators were transformed onto a common scale (from -1 to +1) representing the degree of ‘truth’ of the objective as a fuzzy variable, corresponding to the fuzzy transformation of Gurocak et al. (1998) but emphasizing only two attributes (‘true’ vs. ‘false’). However, unlike Gurocak et al.’s (1998) application of rules to combine the fuzzy sets, the expert system by Paterson et al. (2007) applied fuzzy logic operators. In replacing decision rules with fuzzy logic operators, strong parallels with methodology of preference modelling (a more ‘classic’ MCDA approach, Belton and Stewart, 2002) are achieved. The advantage of this approach is that uncertainties are, in part, already are taken care of by fuzzy set theory.

Paterson et al.'s (2007) expert system shows strong potential as a tool for transdisciplinary research and communication between scientists with other stakeholders (Paterson et al. 2010) and can, in principle, accommodate a large set of indicators. However, as pointed out by Gurocak et al. (1998), the dependence of the system on the definition of the fuzzy transformations remains problematic. Jarre et al.'s (2008) comparison of a rule-based expert system to that of Paterson et al.'s (2007) Fuzzy 'AND' operator found that both methods yield very similar results. These authors concluded that the principal trade-off lies in a mathematical formulation (fuzzy set theory) versus the ease with which the functioning of the expert system can be understood by stakeholders.

MCDA is particularly useful in the context of an EAF where multiple societal objectives need to be addressed in the light of uncertainty and complexity, whereas the choice of methodological details for modelling the decision process is case specific. Expert systems (or knowledge-based tools) as an approach have widely been found useful. There are, however, similarly important methodological considerations to take in the process of modelling with stakeholders which will be detailed in the following sections.

MCDA, such as expert systems, have been demonstrated to be useful in a fisheries management context in particular for supporting management considerations when faced with multiple objectives and offers a way to deal effectively with multiple knowledge sources. This thesis draws on this approach and aims to develop a knowledge-based tool based on the 'proof of concept' prototype expert system developed by Paterson et al. (2007) to assess the implementation efficacy of an EAF in the South African sardine fishery.

2.5. Stakeholder participation in fisheries management and modelling in the southern Benguela

Stakeholder participation and engagement is now considered an essential component of fisheries management and sustainable development practice. Stakeholders are considered individuals or organisations that are affected by or are interested a particular topic or issue. With this definition in mind, stakeholders can include scientists, managers, conservation or NGO groups, or representatives thereof, the industry, as well as members of the public who have an interest in the fishery being addressed. In South Africa, the need for participation by all stakeholders in fisheries management is widely recognised (for example, participation is explicitly included in Chapter 1 (Section 2) of the Marine Living Resources Act No. 18 of 1998). Stakeholder participation is considered well developed within the commercial fisheries sector (Staples, 2010) where fishers, industry and management engage in decision-making. A wider range of stakeholder participation is required in fisheries management, where stakeholder participation is fragmented and is limited to observer positions within some scientific and management working groups (Hara et al., 2014). A more representative stakeholder group would ideally include more participation by stakeholders including fishery rights-holders, members of conservation groups, and academic institutions (Augustyn et al., 2014, Hara et al., 2014).

In moving towards an EAF in South Africa, a strong focus is placed on stakeholder participation. The ERA process sought to bring together stakeholders from a diversity of interests to identify issues of EAF in South African fisheries (Nel et al., 2007). Paterson et al. (2007, 2010) followed a collaborative process for developing the first prototype expert system for EAF implementation efficacy in the South African sardine fishery. The work by these authors has provided strong motivation for interdisciplinary and transdisciplinary approaches to EAF in South Africa, which is expanded upon in this thesis. These processes have been developed in close collaboration with South African government departments and have included participation by stakeholders and decision-makers both within the managing authorities (DAFF and DEA) and outside (such as industry, conservation and academia).

Communication among stakeholders is highlighted as a shortcoming in traditional fisheries management. Similarly, the challenge of reporting the indicators and expert systems to stakeholders is widely documented in the literature (Hammond et al., 1995, Garcia et al., 2000, FAO, 2003, Potts, 2006, Reed et al., 2006, Shields et al., 2006, Mackinson et al., 2011). Expert systems and other multi-criteria decision support tools help in synthesising information and making the method and process transparent and communicable to a broad audience. This is emphasised as the major strength of these tools, but ensuring effective communication is often neglected in practice (Grey and Wiedemann, 1999, Chess et al., 2005, Potts, 2006). Exploring ways of communicating the outputs of models among stakeholders and the general public is considered the final step in indicator development (Schiller et al., 2001, Chess et al., 2005, Potts, 2006). Nevertheless, the process of designing expert systems and the interaction of users with the tool can help to facilitate buy-in to the decision as well as offering ways to improve communication among stakeholders around the problem or decision. The transparency, repeatability and scientific defensibility of the method are essential for application, particularly in a management context (Belton and Stewart, 2002, Goodwin and Wright, 2004).

Models that allow for the detail of input data and calculations to be visible help to make the methodology comprehensible and more acceptable to stakeholders and ultimately useful to the fishery managers (Belton and Stewart, 2002). The choice of aggregation and visualisation methods employed in an expert system is dependent on stakeholder or user preference (Shields et al., 2002, Potts, 2006, Jarre et al., 2008) as the role of expert systems in improving communication is only useful when stakeholders are responsive to information being presented to them (Hammond et al., 1995, Johnson and Chess, 2006, Turhout et al., 2007).

Ensuring that the model outputs are communicated among stakeholders in an easy-to-understand and transparent manner facilitates broader stakeholder buy-in to the decisions made (for example, Garcia et al., 2000, Paterson et al., 2007, Starfield and Jarre, 2011). The dissemination of the model results is one way to include stakeholders in the process. If this is at the end of the process however, stakeholders' acceptance of decisions made may be limited (van den Belt, 2004). Involving stakeholders in a meaningful way in all stages of the modelling process will ensure that stakeholders have a sense of ownership and buy-in to the project, which will increase the likelihood of these tools being incorporated into the decision-making process (Garcia et al., 2000, Belton and Stewart, 2002, Voinov and Bousquet, 2010). Participatory or mediated modelling, defined as the "*use of modelling in support of decision-making processes that involve stakeholders*", provides a structured way to include stakeholders in the modelling process (van den Belt, 2004:14).

Participatory or mediated modelling, a modelling approach which includes stakeholders directly in the modelling process, can help to integrate aspects of complex environmental problems, drawing in ecological, social and economic components of a problem, and facilitates stakeholder participation in an effective manner (van den Belt, 2004). This process helps to improve access to data and puts a quality-check on the data available. As expert systems rely on knowledge from a variety of sources and forms, modelling with stakeholders can help gain access to these knowledges (van den Belt, 2004). Her synthesis provides examples of how mediated modelling can help resolve conflict, build trust among stakeholders, and facilitate mutual group learning processes.

This thesis will draw on the mediated modelling approach to aid the development of the knowledge-based tool developed in Chapters 3, 4 and 5. Focus will be on engaging with relevant stakeholders at each step in the tool development process and ensuring that effective communication among stakeholders is facilitated to enhance the communication function of the indicators and the knowledge-based tool.

2.6. Boundary crossing and social learning

2.6.1. Boundary crossing: Boundary objects and boundary institutions

Managing complex social-ecological systems such as fisheries requires flexible, adaptive, and collaborative approaches. This often means integrating various types of knowledge in decision-making and the collaboration of, and interaction among multiple and diverse groups of stakeholders (Armitage, 2008, Berkes, 2009). Balancing divergent practices, perspectives, and interests in management approaches is therefore needed; otherwise they may become boundaries to effective collaboration.

Boundaries are defined in social science literature as the "*socio-cultural differences leading to discontinuities in action or interactions*" (Akkerman and Bakker, 2011a: 133). Boundaries distinguish something from something else. It is the experience of unfamiliarity that often defines the boundary (Akkerman, 2011, Cremers et al., under review). Boundaries are dynamic and socially constructed for a particular context (Akkerman and Bakker, 2011a) and can be defined by different practices or physical locations such as the boundary between science and policy (Wilson, 2009), or by verbal markers. Verbal boundaries can be observed through use of us versus them language or use of the term boundary or its synonyms (for example; barrier, threshold, or fence) (Cremers, et al., under review).

Many collaborative approaches require continuity across boundaries. Working across boundaries may impede understandings between stakeholders or hamper on-going action. It may also offer a means of continuity and suggests movement across an identified boundary or the co-location of practices across the boundary (Akkerman and Bakker, 2011a). Boundaries can be bridged through the use of artefacts called boundary objects. Star and Griesemer (1989) introduced boundary objects to make sense of the collaboration between scientists and other actors (academic professors, university managers and administrators, and the general public) during the development of a natural history museum. Boundary objects provide a material object to focus interaction and communication around a specific topic or issue (Star and Griesemer, 1989, Guston, 2001). A boundary object offers a means by which to structure discussions between perspectives, translate information across boundaries, and explore how to relate different perspectives to one another while maintaining coherence within their socio-cultural world (Star and Griesemer, 1989, Guston, 2001, Guile, 2011).

Organisations or institutions can support boundary crossing by providing important mediating functions across the boundary and facilitating communication with stakeholders at the boundary (Wilson, 2009). An institution can be an emergent feature of a group sharing common norms and behaviours, or a more structured organisation set up for a specific purpose (Miller, 2012). While the roles of boundary institutions vary in their intended purpose, they share some key characteristics or functions: (i) they allow for participation by stakeholders from both sides of the boundary, (ii) they are accountable to both sides of the boundary and (iii) they help to mediate information flow across the boundary (Guston, 2001). Boundary institutions often provide the space and incentives to create and use boundary objects and tend to be most successful when the principal stakeholders on each side of the boundary rely on the boundary institution to provide the resources (Guston, 2001).

Individuals who participate in boundary institutions can support boundary crossing (Wegner, 2000, Akkerman and Bakker, 2011b). These people are referred to as brokers or boundary crossers (Akkerman and Bakker, 2011b). Brokers are most often members of multiple groups or act as transitions between one group and another and are therefore able to introduce elements of each group to the other (Akkerman and Bakker, 2011b). Establishing interactions between stakeholders involved in different practices offer another means of boundary crossing (Wegner, 2000, Akkerman and Bakker, 2011b). Boundary interactions or boundary practices offer a more sustained interaction across the boundary, for example between disciplinary practices in an interdisciplinary research project (Wegner, 2000).

Boundaries function in distinguishing practices and defining roles and responsibilities (Wilson, 2009). Maintaining boundaries can be important for the legitimacy of some practices (see Wilson (2009) for a detailed discussion on this in the context of the science-policy boundary in European fisheries management). When seeking innovative solutions to complex natural resource problems, encountering boundaries may result in dissonance between stakeholder perspectives or practices. This dissonance may result in tensions or conflict between stakeholders or groups of stakeholders which can make it difficult to meet goals or produce useful findings (Akkerman, 2011, Sol et al., 2013). Boundaries can offer the space for stakeholders to interact, and through interaction, to learn from the very differences that define the boundary (Akkerman and Bakker, 2011b). Learning in this context is seen as the change in practice that occurs during action and interactions at the boundary (Akkerman, 2011, Akkerman and Bakker, 2011b).

2.6.2. Social learning

Collaborative, reflexive learning-based approaches are gaining value in addressing issues associated with managing complex social-ecological systems (Armitage et al., 2008, Berkes, 2009, Rodela, 2011). Social learning has become a normative goal in natural resource management over the past decade (Armitage et al., 2008, Reed et al., 2010, Rodela, 2011) and is defined as the "*collective action and reflection that occurs among individuals and groups as they work to improve the management of human and environmental interrelations*" (Keen et al., 2005:4).

Muro and Jeffrey (2008) provided a review of social learning in participatory natural resource management. As part of their research the authors present a compound model of social learning (Figure 2.5). This figure provides a useful framework for understanding the application of social learning in the context of natural resource management. Social learning is enabled by communication and interaction through a participatory process, but this alone does not ensure social learning. Social learning can contribute to shared understandings, mutual agreement and collective action when the space is created to allow a truly participatory process. This includes creating the space to allow participants or stakeholders involved in a participatory process to recognise other perspectives, making their own and others underlying assumptions and values explicit, allowing for the co-creation of knowledge and improving understanding of complexity of the management system (Muro and Jeffrey, 2008).

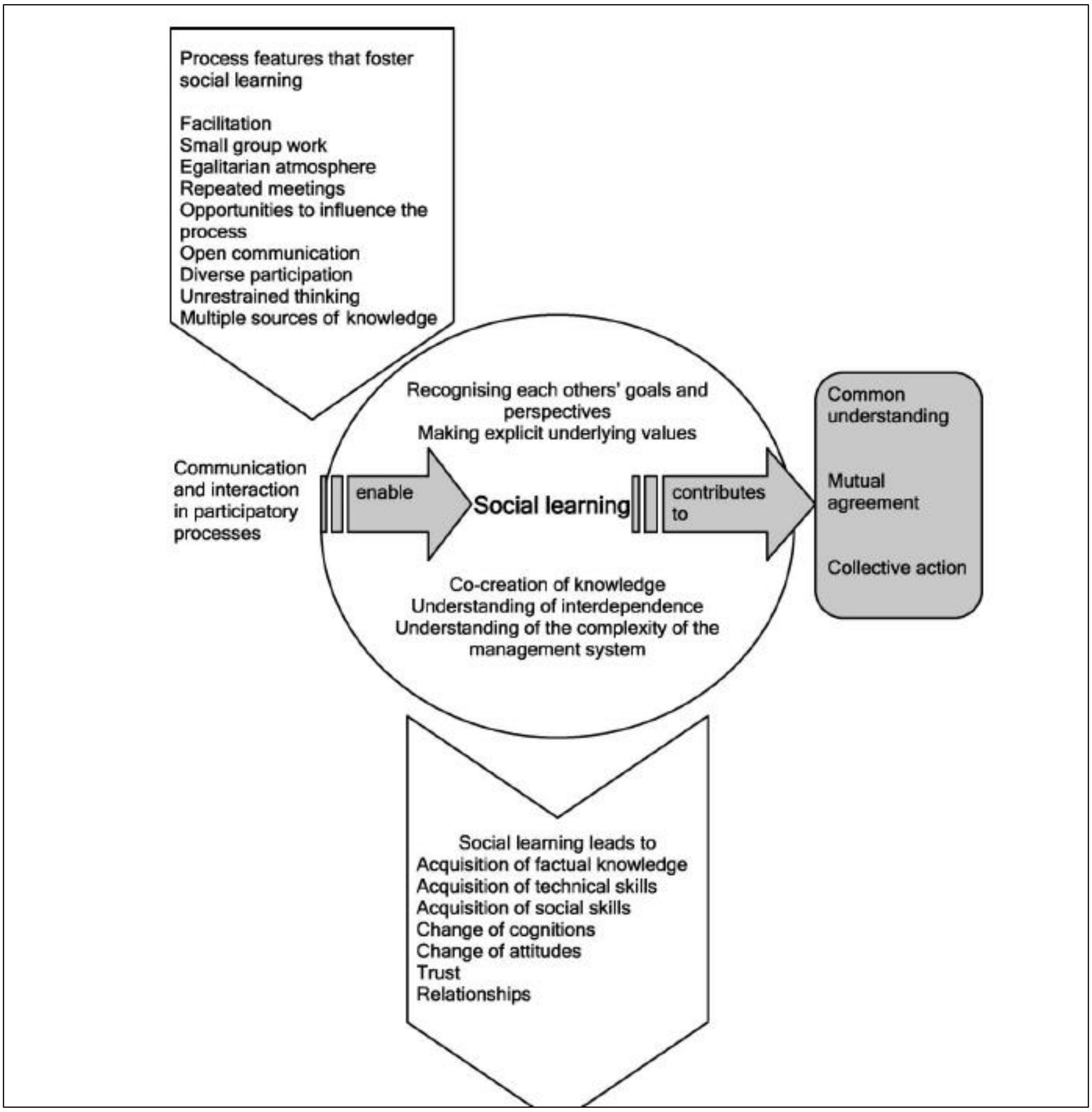


Figure 2.5: A compound model of social learning drawn from literature. Adapted from Muro and Jeffrey (2008).

Following this model, a social learning method is understood as the careful facilitation of learning features within a participatory process. The type of process used as examples by Muro and Jeffrey (2008) include building a group model in water resource management in Switzerland (Pahl-Wostl and Hare, 2004), an EIA for a waste management strategy in Finland (Saarikoski, 2000) and learning for sustainability workshops in India, Bolivia and Mali (Rist et al., 2007), Process features that support social learning included the considered facilitation of the process, group work, repeated meetings and extended contact time (Muro and Jeffrey, 2008). Offering participants in social learning processes the space for open communication and encouraging an equal footing for all stakeholders is important (Muro and Jeffrey, 2008, Cundill and Rodela, 2012). As is including diverse stakeholders and using multiple knowledge sources (Muro and Jeffrey, 2008). The positive outcomes of a successful social learning process are listed in Muro and Jeffrey's (2008) model (Figure 2.5) and include building trust, and changing attitudes and behaviours among stakeholders.

Based on comprehensive literature reviews, Rodela, Cundill, and others have produced a series of review papers which unpack the research perspectives, methodological underpinnings, processes, and outcomes of social learning in natural resource management (Rodela, 2011, Rodela et al., 2012, Cundill and Rodela, 2012, Rodela, 2013). Three research perspectives have been identified in social learning literature (Rodela, 2011). Firstly, learning is observed as an outcome of stakeholders attending events such as participatory workshops. Secondly, social learning is referred to as the change in the way resource management practices are undertaken as the result of interaction through networks; and thirdly, social learning is observed as the broader conceptualisation of learning as an emergent property in social-ecological systems. Rodela (2011) refers to these research perspectives as individual-centric, network-centric, and systems-centric. Some authors emphasise individual learning while others emphasise group learning (Rodela, 2011). Most researchers recognise that interventions, such as participatory workshops, meetings, and multi-stakeholder platforms provide opportunities for social learning (Rodela, 2011).

Interventions such as these offer a platform for exploratory research, supporting social learning through research design, with the outcomes and assumptions to be tested in action (Rodela, 2011). However, few papers include active experimentation on social learning in research projects, rather presenting social learning as hindsight (Rodela et al., 2012). Social learning in natural resource management is often extrapolated from projects or activities used to evaluate other processes such as participation. This is possibly as a result of the role of the researcher involved in evaluating social learning (Rodela et al., 2012). In the natural resource management domain such researchers are very often trained in the natural sciences and borrow practices from social science while maintaining their disciplinary perspectives (Rodela et al., 2012). Consequently, social processes may be evaluated differently than they would be by a social scientist. Interdisciplinary research benefits from a social learning perspective and more experimental, iterative, and reflective methods should be applied to evaluate social learning processes in management interventions (Rodela et al., 2012, Rodela, 2013).

Social learning occurs 'in action', echoing the approach favoured in adaptive management (Armitage et al., 2008, Berkes, 2009) and participatory modelling (for example, Squires and Renn, 2011), and 'in interaction' between participants and the problem situation (Loeber et al., 2007, Cundill and Rodela, 2012). Deliberative interactions among stakeholders from different backgrounds and with different perspectives provide opportunities for social learning (Jiggins, 2007, Cundill and Rodela, 2012). It is during interaction that stakeholders can learn to work together for joint action to develop new and innovative solutions and perspectives on a shared problem (Jiggins et al., 2007, Cundill and Rodela, 2012).

Social learning through sustained interactions can result in renegotiation of relationships, sharing of knowledge and increased trust between stakeholders as well as a re-framing of shared issues as stakeholders interact (Cundill and Rodela, 2012, Sol et al., 2013). The outcomes of social learning processes can be conceptualised on three axes: (i) the co-creation of knowledge around a topic, (ii) the convergence of goals, criteria, and knowledge among stakeholders and (iii) changes in the behaviours, norms, and procedures undertaken in a given context (Jiggins et al., 2007). Change in perception followed by modifications in the behaviour of those involved in social learning processes are considered key outcomes of the process, and it is these changes that influence management outcomes and decision-making processes (Sol et al., 2013).

However, poorly facilitated collaborative processes may have the opposite effect. Unsuccessful participatory projects and processes are much harder to find in the literature and with these stories missing, may bias the reader into thinking that by encouraging participation that social learning will automatically occur and the benefits of this process will follow. Muro and Jeffrey (2008) offer a useful critique of this assertion based on available literature. Mistaken learning, failure to reach agreement or consensus, increased conflict as a result of stakeholder interaction and the influence of power over the process are used as examples of the result of 'failed' social learning through participatory processes (Muro and Jeffrey, 2008). Being conscious of this is important when facilitating and documenting social learning processes.

Social learning can be observed as either an emergent property of stakeholder interactions or as an instrument designed and used in a carefully facilitated process (Wals, 2007, Wals et al., 2009). Facilitated communication and dialogue occurring across different scales of interactions can strengthen social learning outcomes. Deliberate facilitation is required to ensure that effective social learning takes place (Jiggins et al., 2007, Cundill, 2010). Rist et al. (2007) suggest that in addition to creating a favourable social space, facilitators of social learning processes need to invest in social capital and connect levels of knowledge. This requires a move beyond simply involving people representing their sector or discipline. For successful social learning, some commitment to equitable decision-making is required, and conflicts or tensions that may arise through the process should be approached as learning opportunities (Dyball et al., 2007, Akkerman and Bakker, 2011a). Thus, facilitating social learning requires the creation of a "*culture that respects and values diversity, transparency and accountability*" (Dyball et al., 2007). Social learning, therefore, offers the opportunity to take advantage of differences in perceptions, practices and interests by fostering stakeholder interactions (Sol et al., 2013). Joint action can help "*facilitate innovation and possibly foster pathways for positive transitions in social-ecological systems*" (Sol et al., 2013).

There is growing consensus that successful social learning results in improved decision-making (Cundill and Rodela, 2012). Social learning is issue-driven, and has demonstrated through practice to support an improved awareness of human-environment interactions and problem solving abilities of stakeholders involved in these processes (Cundill and Rodela, 2012).

Participatory and adaptive social learning allows stakeholders to consider social and environmental relationships and "*integrates ideas and actions across social boundaries*", allowing for the "*negotiation of learning agendas and indicators of success*" (Dyball et al., 2007:192). The use of boundary objects can facilitate social learning just as social learning helps to integrate ideas and actions across social boundaries (Dyball et al., 2007:192). Indeed, "*social learning practices benefit more from working around material objects than from spending endless hours trying to develop shared visions in the abstract*" (Jiggins et al., 2007:431). By engaging with stakeholders around a common objective, for example, indicators or a model (see for example, Cash et al., 2003) it will be easier to make progress towards a solution to a shared problem.

The social theories of boundary crossing through the use of boundary institutions and boundary objects, and social learning will be applied in Chapter 6 of this thesis. This chapter aims to reflect on the process of participatory modelling through the knowledge-based tool development process and uses these theories to support the observations made.

Chapter 3

Tracking EAF implementation in the South African sardine fishery: Indicators of ecological well-being

3.1. Introduction

An EAF requires addressing a large number of issues, taking into consideration various sources of knowledge and data to do so. It would be inefficient, if not impossible, to measure everything relating to an EAF in a fishery (FAO, 1999, Rochet et al., 2007). In the context of an EAF, the role of indicators in supporting the decision-making process cannot be overlooked. Indicators provide an efficient means of distilling key elements of a fishery to produce information on the state of the ecosystem and track progress towards meeting management objectives (Garcia et al., 2000, FAO, 2003, Rice, 2003, Rochet and Trenkel, 2003, Jennings, 2005).

Indicators can help track progress towards meeting management objectives by linking societal goals and objectives to management actions (Garcia et al., 2000, FAO, 2003, Rice, 2003, Rochet and Trenkel, 2003, Jennings, 2005), and are often used to help bridge the gap between science and decision-making and policy (Potts, 2006, Turnhout et al., 2007). Indicators can be used to promote understanding and consensus building among stakeholders, as well as communicating trends and progress made in management processes (Garcia, 2000, Rice, 2003, Degnbol and Jarre, 2004, Rice and Rochet, 2005, Jennings, 2005, Potts, 2005, Rochet et al., 2007, Turnhout et al., 2007).

A thorough issue and objective identification process should be the first step in any effort to develop indicators for an EAF (Garcia et al., 2000, Rice and Rochet, 2005). A number of frameworks have been developed as useful tools for issue identification and objectives development in fisheries management; these include the Pressure-State-Response (PSR) and Drivers-Pressure-State-Impact-Response (DIPSR) frameworks and hierarchical trees (FAO, 2003). The DPSIR framework, an extension of the PSR framework developed by the OECD (1993) is presented in Figure 3.1. This framework captures the interactions between the environment and society and is used to assess environmental problems and identify possible management actions (FAO, 2003). The DIPSR framework distinguishes between *driving forces* exerting *pressures* on an ecosystem, which in turn result in changes to the *state* of the ecosystem, and may *impact* the broader socio-ecological system. Management provides *responses* to these impacts; these responses either affect the driving forces, or directly affect the pressures on the ecosystem. Pressure and state indicators are usually linked to ecological or technical objectives and response and impact indicators are often linked to institutional objectives (Degnbol and Jarre, 2004).

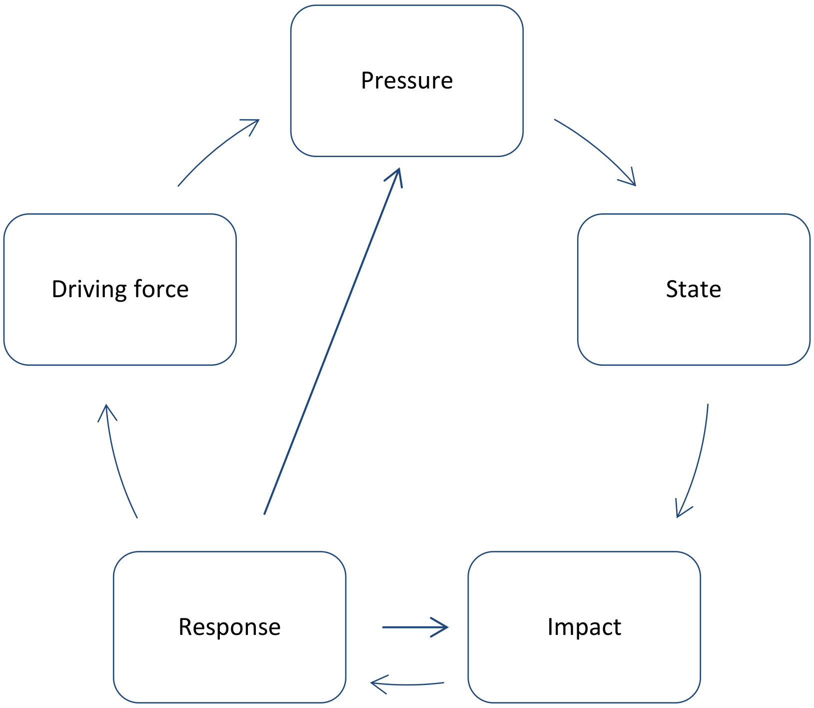


Figure 3.1: The DIPSR framework widely used to identify indicators in the management process (OECD, 1993).

To assist in identifying the main issues a fishery is faced with when implementing an EAF and Ecological Risk Assessment has been adopted in Australia (Fletcher et al., 2002) and South Africa (Nel et al., 2007, Paterson et al., 2007). This approach provides a structured method to help tease out all the issues a fishery faces when implementing an EAF (FAO, 2003). The ERA applies a hierarchical tree to deal directly with issues and objectives. In the ERA, the three overarching goals of EAF, as presented in the FAO EAF framework (see Figure 1.1) are broken down into eight key components and disaggregated further into specific management objectives to which indicators can be linked (see Nel et al., 2007).

In South Africa, the Ecological Risk Assessments (ERA) and ERA review processes have supported the development of response and impact indicators for all three dimensions of an EAF (Nel et al., 2007, Paterson and Petersen, 2010, Paterson et al., 2010). Progress in compiling pressure and state indicators for the ecological well-being dimension of EAF in the South African sardine-directed fishery have been done to some extent by Fairweather et al. (2006a, 2006b) and Shannon et al. (2010). These indicators were used in developing a 'proof of concept' expert system for tracking the implementation of EAF in the South African sardine fishery (Paterson et al., 2007, Jarre et al., 2008).

Paterson et al. (2007) placed emphasis on stakeholder participation over the fine-tuning of their model. Since this first prototype was developed further work has been done on refining the indicator suite and updating the scientific database. While Paterson et al. (2010) has proceeded in putting together a first prototype for the human dimension, indicators for the ecological well-being dimension of EAF in the sardine fishery required further refinement.

This chapter aims at developing a suite of indicators linked to ecological well-being objectives for EAF implementation in the South African sardine fishery. The time series of indicators identified through consultation with stakeholders and the methodology used in calculating each indicator are presented in detail.

3.2. Objectives for ecological well-being and EAF implementation in the South African sardine fishery

The management objectives for an EAF in the South African sardine fishery were first developed through the Ecological Risk Assessment workshops held in 2007 (Nel et al., 2007). These a multi-stakeholder workshops included representation from fisheries management, conservation, academic institutions and industry and the objectives developed here are widely accepted as appropriately representative of the state of EAF in South Africa. An extensive discussion on objectives for the sardine fishery was further held at a workshop in Pringle Bay in November 2007 (Jarre et al., 2007) and further discussions with the EAF Scientific Working Group in October 2009 (EAF-SWG, 2009) resulted in the revision of the objectives' hierarchy for EAF in the sardine fishery (Figure 3.2).

A hierarchical tree approach was applied for identifying objectives for EAF in the South African sardine fishery, for the ecological well-being dimension, and the issues relating to pressure and state indicators in the DIPSR framework were identified.

The objectives' hierarchy has been divided into separate state and pressure objectives to help distinguish between pressures to the ecosystem which can be controlled through management intervention in the fishery and external factors which indicate changes to the ecosystem state beyond the scope of direct fishery management (Degnbol and Jarre, 2004, Jennings, 2005). This hierarchy has been accepted by the EAF-SWG as a suitable framework for the identification of issues relating to EAF implementation in the sardine fishery (EAF-SWG, 2009). This hierarchy provides the platform on which this chapter is built.

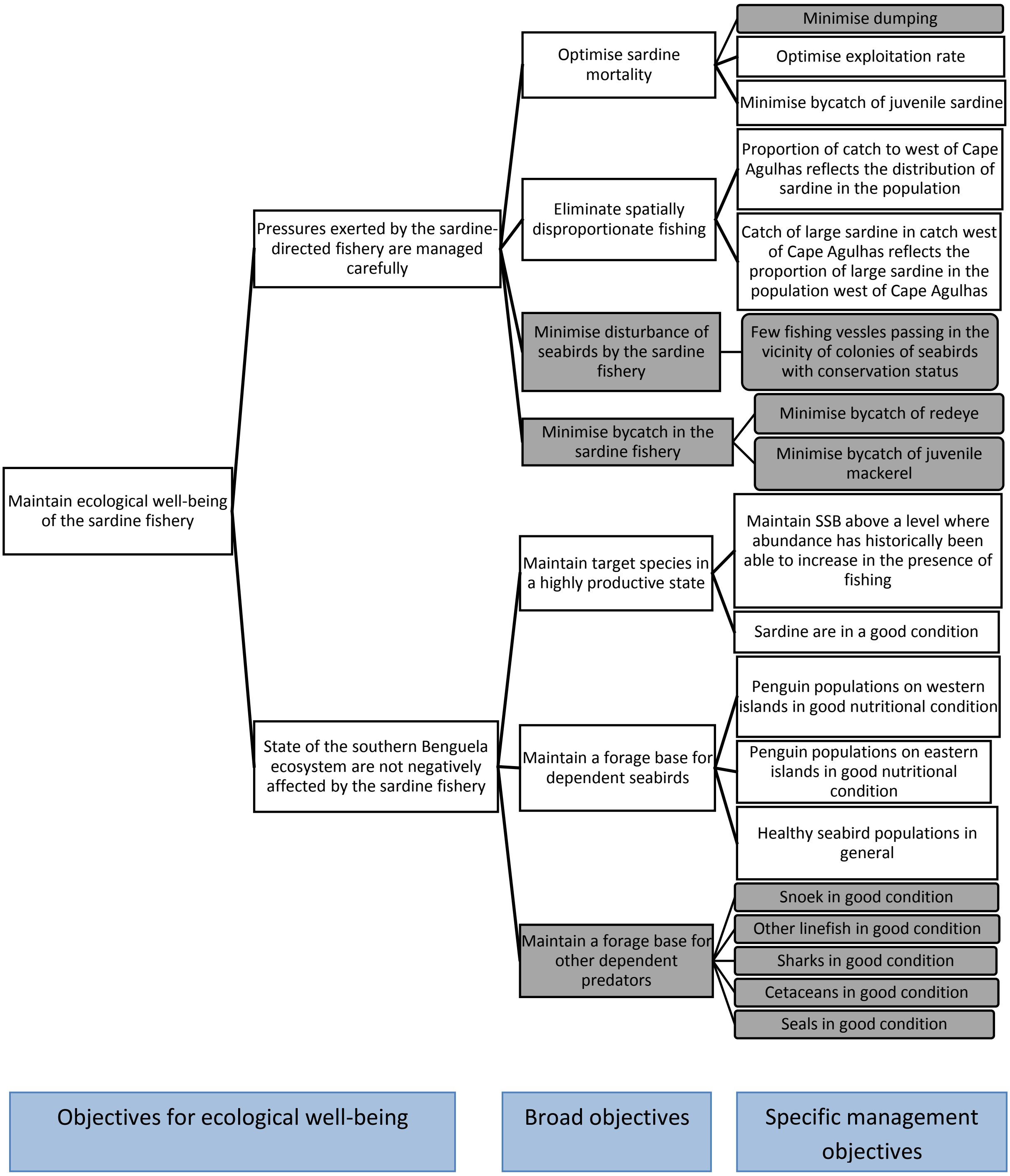


Figure 3.2: The objectives' hierarchy representing the goals and increasingly specific objectives selected to monitor and evaluate the implementation efficacy of an EAF in the sardine-directed fishery. The objectives 'switched off' in the current assessment are shaded in grey.

3.3. Approach to identifying indicators

Figure 3.2 presents the objectives' hierarchy in four levels. An overarching objective for EAF implementation in the South African sardine fishery is split into broad objectives for pressure and state. The hierarchy is further disaggregated into a suite of specific management objectives to which indicators can be linked. I accepted that, at the time this research was conducted, this suite of objectives reflected the current issues and priorities for EAF implementation in the ecological well-being dimension for the sardine fishery.

The objectives' hierarchy was the result of numerous hours of consultation with key experts in EAF at the time (Jarre et al., 2007, EAF-SWG, 2009). During indicator development, I kept any discussions on the management objectives to a minimum, assuming that as this had already been through an extensive consultative process they would be appropriate for research. However, some changes were made to the wording of objectives when stakeholders who were consulted during indicator development process presented a strong motivation for such change, for example to improve clarity in the objective. Any edits to the objectives were cosmetic, as only the wording was changed, and did not affect the objectives' meaning.

Linking ecological indicators to the specific management objectives shown in Figure 3.2 was the first step in developing the knowledge-based tool. A literature review was conducted to identify existing indicators that would address the management objectives. In addition, experts were identified to assist in identifying indicators (experts consulted are listed in Table 3.1). The experts consulted were affiliated with well-established research groups, such as the Marine Research Institute (MA-RE), Avian Demography Unity (ADU) at UCT or are in-house experts with relevant South African government departments (DAFF, DEA). Interviews were held with the identified experts to discuss possible indicators and source relevant data. Experts consulted here are considered specialists in their relevant fields and are also stakeholders in this process as they work directly on EAF-related issues considered important in this fishery. The result of these interviews and the literature review was a suite of candidate indicators; a full list of potential indicators is presented in Appendix 1.

Any indicators selected to support an EAF should be readily observable, linked to management objectives and be acceptable to stakeholders (Degnbol and Jarre, 2004). Rice and Rochet (2005) further add to the properties of indicators, presenting a suite of criteria against which to select indicators. These include the concreteness and theoretical basis of an indicator, cost effectiveness, measurability, availability of historical data, public awareness and the sensitivity and responsiveness of the indicator to management action (Rice and Rochet, 2005). No single indicator will have all these properties. However, the choice of indicators can be supported and potential trade-offs between candidate indicators can be related to these criteria.

Only the most representative and practically achievable indicators were selected to measure progress towards meeting the objectives of EAF implementation in the sardine fishery. The indicators that were finally selected were required to meet the following criteria (Garcia et al., 2000, Degnbol and Jarre, 2004, Rice and Rochet, 2005, Potts, 2005, Shin et al., 2010):

i. Be easily measured using long term reliable data sets,
ii. Show a trend representative of expert understanding of the indicator (ecological significance and sensitivity to fishing pressure), and
iii. Be acceptable to most stakeholders.

The suite of candidate indicators was narrowed down to ensure they were most appropriate to the above criteria. These indicators were presented at two stakeholder meetings. The first meeting formed part of a meeting of the EAF-SWG (2 March 2011) and the second as part of a meeting of the SWG-PEL (17 May 2011). These two groups consisted of some of the experts who were consulted in identifying indicators, as well as other stakeholders, from the fishing industry, conservation NGOs and the University of Cape Town, who have relevant experience with one or more of the areas addressed by the management objectives. A list of stakeholders is included in Tables 3.2 and 3.3. Feedback from these groups was valuable in selecting appropriate indicators. Stakeholders in both meetings were asked to provide feedback on the acceptability of the indicators in meeting the management objectives, and to ensure that they were the most appropriate given the constraints and available scientific information. From these discussions a final suite of indicators was selected, these are linked to the management objectives and presented in Figure 3.3. Table 3.1 provides a detailed description of each indicator and lists the experts consulted when developing the indicator. Section 3.3 details the indicators selected and describes the related indicator time series.

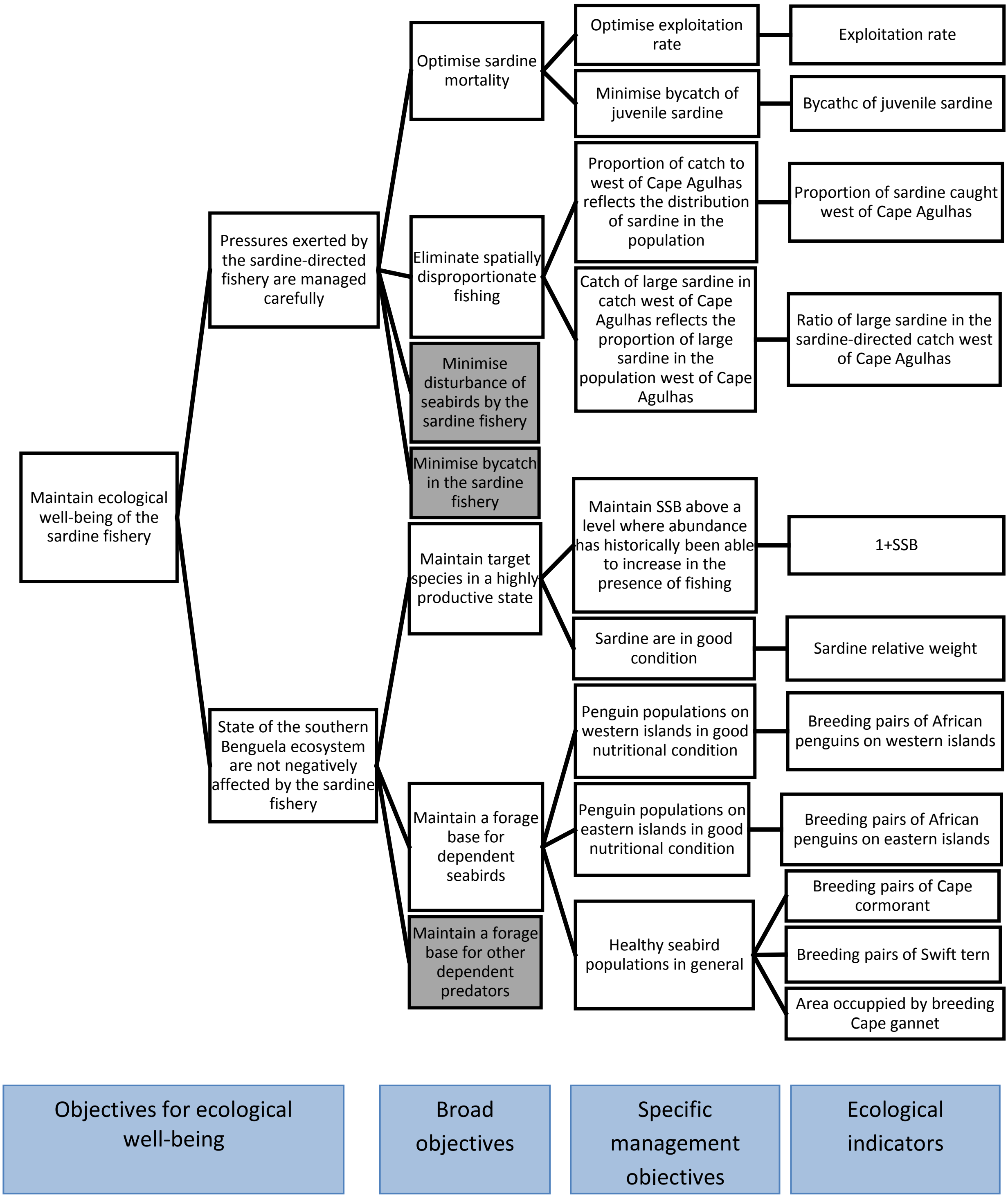


Figure 3.3: The final suite of indicators linked to specific management objectives for ecological well-being in the South African sardine fishery. Ecological indicators are linked to objectives for Pressure and State. The objectives 'switched off' in the current assessment are shaded in grey.

Table 3.1: The description of the ecological indicators identified for each management objectives. The experts consulted in identifying indicators and their professional affiliation are included.

Broad objective	Management objective	Indicator	Description	Expert consulted and professional affiliation
Pressures exerted by the sardine fishery				
Optimise sardine mortality	Optimise exploitation rate	Exploitation rate	Measure of fishing intensity Proportion of the total mortality caused by fishing (E= F/Z)	Tracey Fairweather (DAFF) Deon Durholtz (DAFF)
	Minimise bycatch of juvenile sardine	Bycatch of juvenile sardine	The bycatch of juvenile sardine in the total sardine-directed catch	Janet Coetzee (DAFF)
Eliminate spatially disproportionate fishing	Proportion of catch west of Cape Agulhas reflects the distribution of sardine in the population	Proportion of sardine caught west of Cape Agulhas	The sardine-directed catch to the west of Cape Agulhas reflects the distribution of sardine in the total population in the previous year	Carl van der Lingen (DAFF) Jan van der Westhuizen (DAFF)
	Catch of large sardine in catch west of Cape Agulhas reflects the proportion of large sardine in the population west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	The proportion of large sexually mature sardine in the sardine-directed catch off the west coast reflects the proportion of large sardine in the total population	Carl van der Lingen (DAFF) Jan van der Westhuizen (DAFF)
State of the southern Benguela ecosystem				
Maintain target species in a highly productive state	Maintain spawner stock biomass (SSB) above a level where abundance has historically been able to increase in the presence of fishing	1^{+}SSB	Model predicted 1^{+}SSB	Janet Coetzee (DAFF) Carryn de Moor (MARAM, UCT)
Maintain target species in a highly productive state	Sardine in good condition	Sardine relative weight	Median value of relative condition of the sardine population	Hilkka Ndjuala (MA-RE, UCT) Carl van der Lingen (DAFF)
Maintain forage base for dependent seabirds	African penguin populations on western islands in good nutritional condition	Number of breeding pairs of African Penguins on western islands	Breeding numbers of African Penguins on western islands	Rob Crawford (DEA) Les Underhill (ADU, UCT) Richard Sherley (ADU, UCT) Lauren Waller (ADU, UCT & CapeNature)

Broad objective	Management objective	Indicator	Description	Expert consulted and professional affiliation
	African penguin populations on eastern islands in good nutritional condition	Number of breeding pairs of African Penguins on eastern islands	Breeding numbers of African Penguins on eastern islands	Rob Crawford (DEA) Les Underhill (ADU, UCT) Lorien Pichegru (ADU, UCT) Lauren Waller (ADU, UCT)
	Healthy seabird populations in general	Number of breeding pairs of Cape cormorants	Breeding pairs of Cape cormorants on western islands	Rob Crawford (DEA) Les Underhill (ADU, UCT)
		Number of breeding pairs of Swift terns	Breeding pairs of Swift terns	Rob Crawford (DEA) Les Underhill (ADU, UCT)
		Number of breeding pairs of Cape gannets	Area (ha) occupied by Cape gannets on western islands	Rob Crawford (DEA) Les Underhill (ADU, UCT)

Table 3.2: Stakeholders present at the EAF-SWG meeting on the 3 March 2011.

Name	Institution/ Affiliation	Area of expertise
Carl van der Lingen	DAFF	Sardines and EAF
Astrid Jarre	Ma-Re UCT	EAF
Lynne Shannon	Ma-Re UCT	EAF
Rob Crawford	Oceans and Coasts, DEA	Seabirds
Herman Oosthuizen	Oceans and Coasts, DEA	Top predators
Johan de Goede	DAFF	Sardines and management
Newi Amakhado	Oceans and Coasts, DEA	Seabirds
Samantha Petersen	WWF South Africa	EAF

Table 3.3: Stakeholders present at the SWG-PEL meeting on the 17 May 2011.

Name	Institution/ Affiliation	Area of expertise
Janet Coetzee	DAFF	Small pelagics
Jan van der Westhuizen	DAFF	Small pelagics
Yonela Geja	DAFF	Small pelagics
Johan de Goede	DAFF	Small pelagics
Carl van der Lingen	DAFF	Small pelagics
Sobahle Somhlaba	DAFF	Small pelagics
Nandipha Twatwa	DAFF	Small pelagics
Deon Durholtz	DAFF	Small pelagics
Carryn de Moor	MARAM UCT	Fishery stock assessment
Doug Butterworth	MARAM UCT	Fishery stock assessment
Fannie Shabangu	DAFF	Small pelagics
Mzwamadoda Phillips	DAFF	Small pelagics
Ashok Bali	DAFF	Small pelagics
Astrid Jarre	Ma-Re UCT	EAF

Some of the objectives could not be linked to indicators, the reasons for this are provided in section 3.4. These objectives remain in the objectives' hierarchy (shaded in grey in Figures 3.2 and 3.3), as it they are, or might easily become, important issues relating to EAF implementation. Once the indicators were finalised, the time series underpinning each indicator was assembled with the help of the relevant experts (see Table 3.1).

The selected time series spans the period 1987-2009. This timeline was chosen based on the availability of historical data, in particular accurate hydroacoustic survey data (available from 1984) and spatially explicit catch data, which was only consistently monitored from 1987. The data were collected for this chapter at the end of 2010, however as a result of delays in data processing the time series were compiled to 2009.

Many of the indicators are directly sourced from long term monitoring programmes and did not require any further processing or analysis. Some indicators in the final selection had been developed previously, but required revision, for example sardine exploitation rate (Fairweather et al., 2006a). Indicators of spatially disproportionate fishing had not yet been developed and were calculated specifically to use this in this context.

3.4. Indicator selection and calculation

A final suite of eleven indicators were selected for inclusion in the knowledge-based tool (see Figure 3.3). How the indicators were defined and calculated and the resultant indicator time series are presented below.

Exploitation rate

The exploitation rate of a fishery is a measure of fishing intensity, defined as the proportion of mortality caused by fishing (Fairweather et al., 2006a). Exploitation rate has been shown by Fairweather et al. (2006a) to be a useful pressure indicator for managing the sustainable fishing of South African sardine. The annual exploitation rate for the sardine-directed fishery was calculated for the years 1987-2009 using the equation:

(3.1)

$$E_i = \frac{F_i}{Z_i}$$

Where F_i is fishing mortality and Z_i is total mortality. Sardine fishing mortality (F_i) was calculated as:

(3.2)

$$F_i = \frac{C_i}{N_i}$$

Where N_i is the annual biomass estimates from the spawner biomass survey and C_i is the annual total commercial catch. Total mortality was calculated from the Beverton and Holt (1957) expression relating total mortality (Z) and average size in the catch:

(3.3)

$$Z = \frac{(L_\infty - L_{avg})K}{L_{avg} - L_c}$$

In this expression, K and L_∞ are von Bertalanffy parameters for sardine, L_{avg} is the average length of sardine in the catch and L_c is the size at first capture calculated as the first 0.5cm length-group that accounted for at least 10% of the cumulative catch. The von Bertalanffy parameters were calculated from size at age data sampled annually for the years 1993, 1994, 1996, 2000-2004 and 2006-2009 by D.Durholtz (DAFF) and compared to von Bertalanffy parameters calculated by Kerstan for the 1990s (Fairweather et al., 2006a). The temporal overlap in analysis was used to ensure consistency and account for any reader effect between data sets. Sardine growth models were calculated from the size at age data and the von Bertalanffy parameters K and L_∞ derived using the Excel add-in *Solver*. Total mortality was calculated annually for three separate von Bertalanffy parameter series, (i) Kerstan von Bertalanffy parameters (KvB), (ii) Durholtz von Bertalanffy parameters estimated across the time series (DvB1) and (iii) year specific Durholtz von Bertalanffy parameters (DvB2).

Figure 3.4 presents the time series for sardine exploitation rate calculated from DvB1. Exploitation rate was relatively high from 1987-1990, ranging from 0.36-0.85; this period was followed by a large decline from 0.79 in 1990 to 0.11 in 1991. An overall increase in exploitation occurred over the period 1992-1996, but from 1997-2004 exploitation rates were relatively low following the recovery of sardine stocks and careful management of the fishery. Exploitation rate increased substantially from 2005, peaking at 0.76 in 2007. This increase can be attributed to a drastic decline in the sardine population over this period and a slower rate of response by the fishery to this drop in biomass. The following years show a decrease in the exploitation rate as the sardine population stabilised and the management response in terms of TAC allocation was better matched the available population biomass.

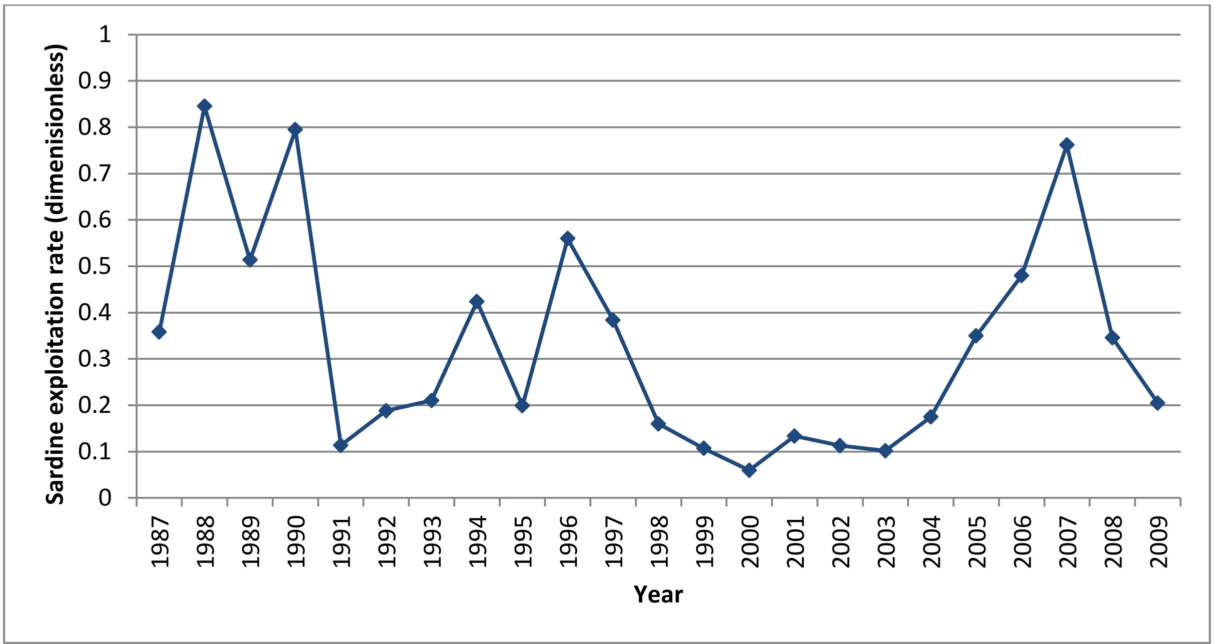


Figure 3.4: Sardine exploitation rate calculated from Durholtz von Bertalanaffy parameters estimated across the time series (DvB1).

The experts consulted considered the exploitation rate calculated from the DvB1 as the most appropriate indicator to meet the objective of optimising exploitation rate in the South African sardine fishery. This time series takes into consideration a longer and more recent sample of sardine age-at-size data and therefore accounts for more of the changes in sardine growth over the period studied. The year specific DvB parameters (DvB2) might be more accurate, but as this represents only 12 years of samples, the time series would be incomplete. Extrapolating the values across the time series was considered appropriate in this context as it would allow better comparison to the other indicators. Exploitation rate calculated from the revised data differs quite substantially from that published in Fairweather et al. (2006a). To explain this discrepancy in the time series, Figure 3.5 compares the indicator of exploitation rate presented in Figure 3.4 (DvB1) to:

i. The previously calculated exploitation rate published in Fairweather et al. (2006a),

ii. KvB, and

iii. DvB2.

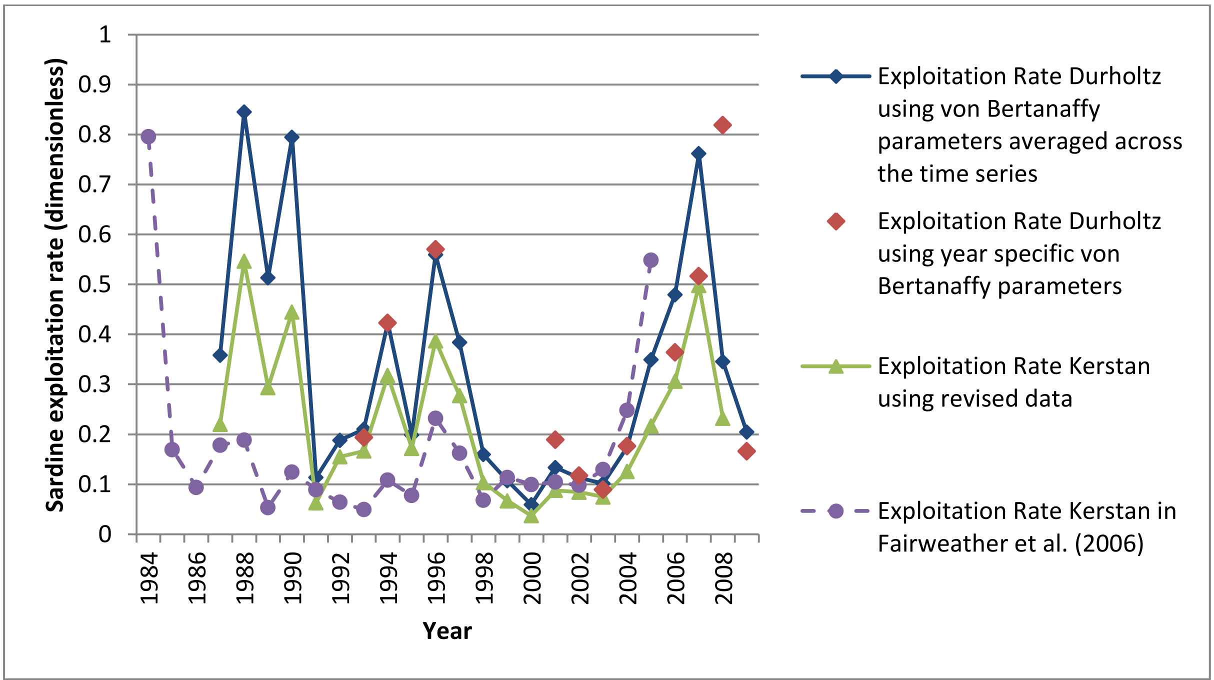


Figure 3.5: Sardine exploitation rate calculated for (i) DvB1, (ii) the previously calculated exploitation rate published in Fairweather et al. (2006), (iii) KvB and (iv) DvB2.

Fairweather et al. (2006a) presented an exploitation rate with very low values, with only two years in the time series exceeding an exploitation rate of 0.25 (Figure 3.5). The departure in exploitation rate between that calculated by Fairweather et al. (2006a) and others presented in Figure 3.5 can be attributed to the revision of the data sets underlying this indicator. The annual mass of sardine-directed catch and length frequency data was revised in 2008 to account for subjectivity in landing allocation at monitoring points and to correctly assign bycatch using a consistent cut-off for allocating catch to bycatch landings (J. van der Westhuizen, Branch Fisheries, DAFF, pers. comm.). This method was applied retrospectively to the time series using fishery data collected at landing sites, and resulted in an increase in the mass of sardine-directed catch, albeit not uniformly, from the catch data used in Fairweather et al. (2006a). Abundance estimates of sardine in the November spawner biomass surveys have been revised to take into account advances in acoustic technology and correct for biases such as receiver saturation, acoustic signal attenuation and target strength (Coetzee et al., 2008a). Biomass was considered to be underestimated using previous techniques (Coetzee et al., 2008a).

Calculating fishing mortality using the revised data sets has resulted in the exploitation rate returning much higher values, as can be observed in Figure 3.5. Exploitation rates calculated with the revised data series demonstrate the same trends over time, with the exploitation rate based on von Bertalanffy parameters calculated by Durholtz resulting in even higher values than the exploitation rate based on Kerstan's parameters. At meetings held with the EAF-SWG and SWG-PEL stakeholders expressed some concern over the high values of exploitation rate presented to them, however they agreed that the methodology and data used to calculate the indicator values was appropriate.

<u>Percentage bycatch of juvenile sardine in the sardine-directed catch</u>

Bycatch, the incidental catch of non-target species by a fishery, is an important management issue in all South Africa fisheries. Juvenile sardine are caught as bycatch in both the sardine-directed and anchovy directed fisheries. Bycatch in both fisheries is limited through permit conditions and an annual total allowable bycatch limit is set for the bycatch of juvenile sardine in the anchovy directed fishery. Increasing concerns over the amount of juvenile sardine caught as bycatch in the sardine-directed fishery has resulted in an indicator of juvenile sardine bycatch being developed.

The percentage bycatch of juvenile sardine caught in the sardine-directed fishery was calculated as the proportion of juvenile sardine caught in the total sardine-directed catch each year using the equation:

$$\text{Percentage bycatch of juvenile sardine} = \frac{\text{Mass of juvenile sardine caught in the sardine directed catch } (t)}{\text{Total mass of sardine caught by the sardine directed fishery } (t)} * 100 \quad (3.4)$$

Estimates of the biomass of sardine caught each year are collected and recorded by fishery inspectors and monitors at designated landing sites. Commercial landings are weighed, the total mass of each species per set is estimated from the total tonnage landed and the vessel skipper's estimate of species composition of each set is recorded. In addition, commercial catches are sampled for size composition and biological characteristics. The numbers of fish in each 0.5 cm size group are sampled daily and provide a length frequency estimate for each landing. This information is collected and retrospectively analysed by DAFF to provide an estimate of the landings by the sardine-directed and bycatch fisheries, as well as a length frequency of commercial landings each year. The length frequency data for the total sardine-directed catch was converted to mass using a length/mass relationship given in van der Lingen et al. (2006).

Juvenile sardine are defined as the sexually immature sardine in the population each year. An annual cut-off length of juvenile sardine is determined annually from modal length analysis of acoustically weighted length frequencies derived from the May recruit survey (Coetzee, 2006, Coetzee and Merkle, 2007). Prior to 1996 a standard annual cut-off length of 15.5 cm was observed, since then cut-off lengths have varied, ranging from 11cm to 17 cm.

Figure 3.6 presents the bycatch of juvenile sardine as a percentage of the total sardine-directed catch and the annual cut-off length of juvenile sardine. Bycatch varies annually but a trend can be detected, with high bycatch rates from 1992-1996, 1999-2000 and 2002-2003. These periods were characterised by relatively high sardine recruitment as detected in the May sardine recruitment surveys. The early to mid-1990s are characterised by relatively low, but increasing biomass while the early 2000s sardine biomass was at levels similar to those in the 1960s (Coetzee et al., 2008a). From 2004 a period of prolonged poor recruitment occurred resulting in low biomass from 2005 (Coetzee et al., 2008a). In 1999 bycatch was high, and although recruitment for that year was low the previous year experienced exceptionally high recruitment, making it possible that some juveniles from this cohort were caught in 1999. When good sardine recruitment occurs there are more juvenile sardine in the population, and it is more likely that the sardine-directed fishery will be catching juveniles along with adult sardine. In years of low biomass and good recruitment bycatch is even more likely.

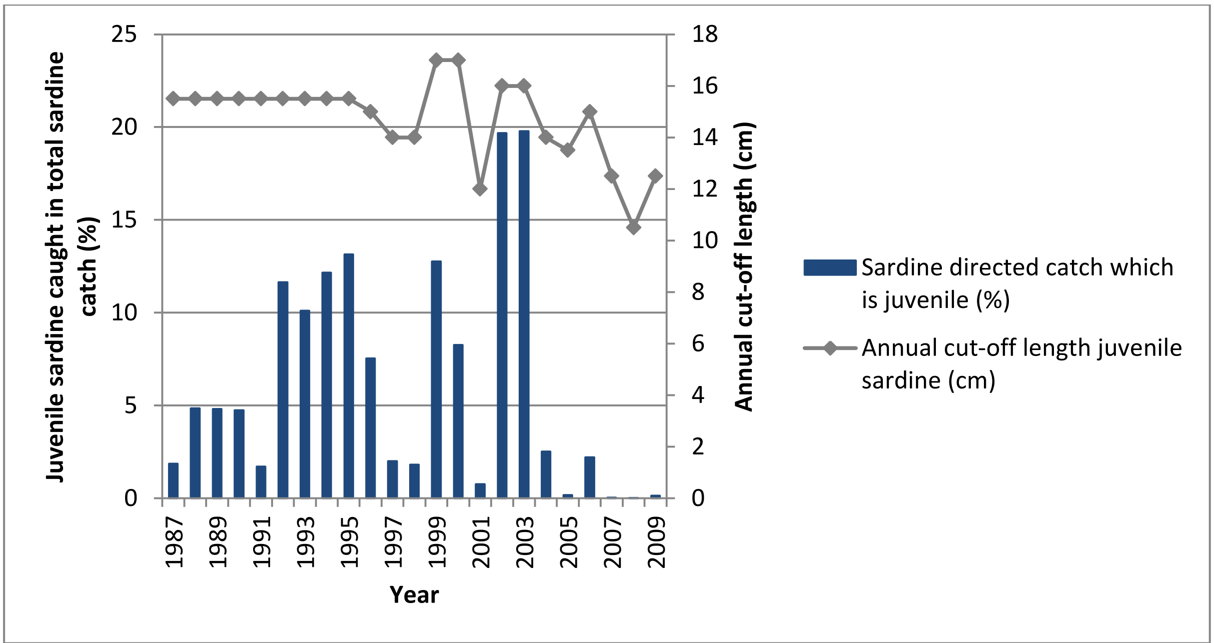


Figure 3.6: The percentage of juvenile sardine caught in total sardine-directed catch each year, and the cut-off length for juvenile sardine varying annually from 1996.

The removal of juvenile sardine from the ecosystem may have serious consequences to recruitment in certain areas. The resultant indicator time series corresponds to stakeholder and management concerns over bycatch in the sardine-directed fishery. In the late 1990s concerns were raised that the small pelagic fishery was possibly targeting adult sardine for bycatch in the anchovy fishery, thereby exceeding the sardine TAC (Fairweather et al., 2006a). In September 2002 further concerns were raised as vessels were thought to be targeting juvenile sardine and landing them as directed catch (Fairweather et al., 2006a). A flow chart was developed to assist fishery inspectors in classifying landings more accurately, however it is thought that bycatch of juvenile sardine is being underestimated and small sardine are possibly discarded at sea. Juvenile sardine make up very little of the commercial landings for 2004-2009, but this could be attributed to poor recruitment over this time period.

Proportion of sardine caught west of Cape Agulhas

Since 1997 a significant eastward displacement of sardine biomass and catches along the South African coast has occurred (Figures 2.4 and 3.7). The spatial change in the distribution of the sardine population has raised concerns among stakeholders that the remaining population of the west coast may be fished too heavily, particularly as the processing facilities are predominately situated on the west coast. Currently, management of the fishery does not account for spatial differences in the population. A mismatch between fishing effort and fish abundance (Coetzee et al., 2008b) may result in genetic depletion of the remaining west coast sardine or cause unsustainably high fishing mortality in the area west of Cape Agulhas (WoCA; Shannon et al., 2006). Spatial indicators have been suggested for monitoring spatially disproportionate fishing in South Africa (Shannon et al., 2003).

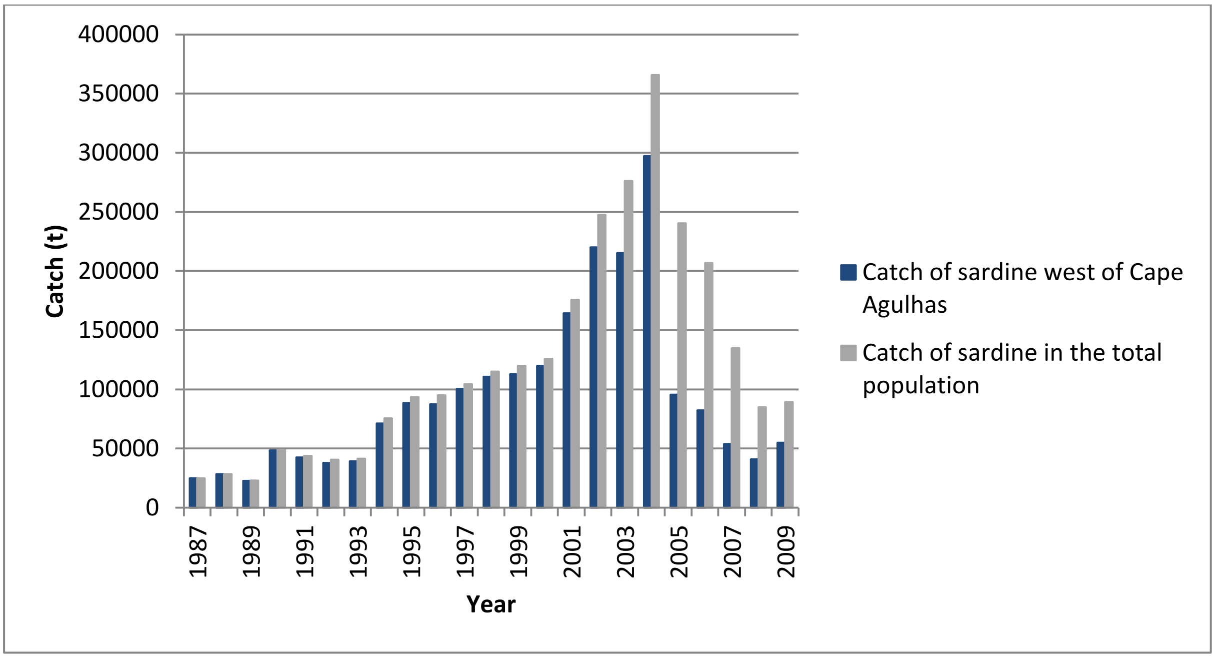


Figure 3.7: The quantity of sardine caught west of Cape Agulhas and the total annual sardine-directed catch.

By ensuring that the proportion of sardine caught on the west coast mirrors of the distribution of the fish population the impacts of spatially disproportionate fishing could be minimised. To monitor the impact of fishing on the population WoCA, the catch of sardine WoCA was calculated as the proportion of the sardine biomass found WoCA in the previous year by the equation:

$$\text{Proportion of sardine caught WoCA} = \frac{\text{Sardine caught WoCA in year } n}{\text{Sardine in the population WoCA in year } (n-1)} \tag{3.5}$$

The total commercial catch of sardine is recorded annually by DAFF and is separated to reflect catch by mass (in tons) of sardine east of Cape Agulhas (EoCA) and WoCA. Annual sardine biomass in the population, separated into the areas EoCA and WoCA, is estimated during hydroacoustic surveys conducted in November each year.

The proportion of sardine caught WoCA to the sardine biomass situated WoCA in the previous year's survey is presented in Figure 3.8. From 1987-2005 the proportion of sardine caught WoCA to sardine biomass WoCA in the previous year has been consistently below 40%, i.e. less than 40% of the population situated WoCA was caught in the sardine-directed fishery (Figure 3.8). A peak at 40% occurred in 1997, a year characterised by high sardine recruitment following a year of very low biomass. After 1997, an increase in sardine biomass resulted in fewer fish being caught in subsequent years, from between 10% to just over 20% from 1998-2001. In 2006, however, a huge increase in the proportion of sardine caught WoCA was recorded. More fish were caught WoCA than were available in the population in this area in the previous year (109%). This is an anomalous result, but can be explained by a number of factors:

i. A drastic decline in sardine biomass occurred in period 2003-2005 (from over 1 300 000t in 2003 to 75 600t in 2005, see Figure 3.11),

ii. A very low period of sardine recruitment occurred during 2004-2005, so not many sardine were available to the fishery in 2006 (DAFF, 2010), and

iii. Despite the drastic decline in sardine biomass in the mid-2000s, the TAC allocation did not correspond to this decline, the OMP in use at the time required only a 10% chance in TAC from the previous year (de Moor et al., 2011).

These factors may have resulted in the high value returned in 2006. However, the biomass surveys conducted annually are characterised by a snapshot of the sardine in the population as a result, these surveys may not have detected the entire sardine population in that year (see Coetzee et al., 2008b).

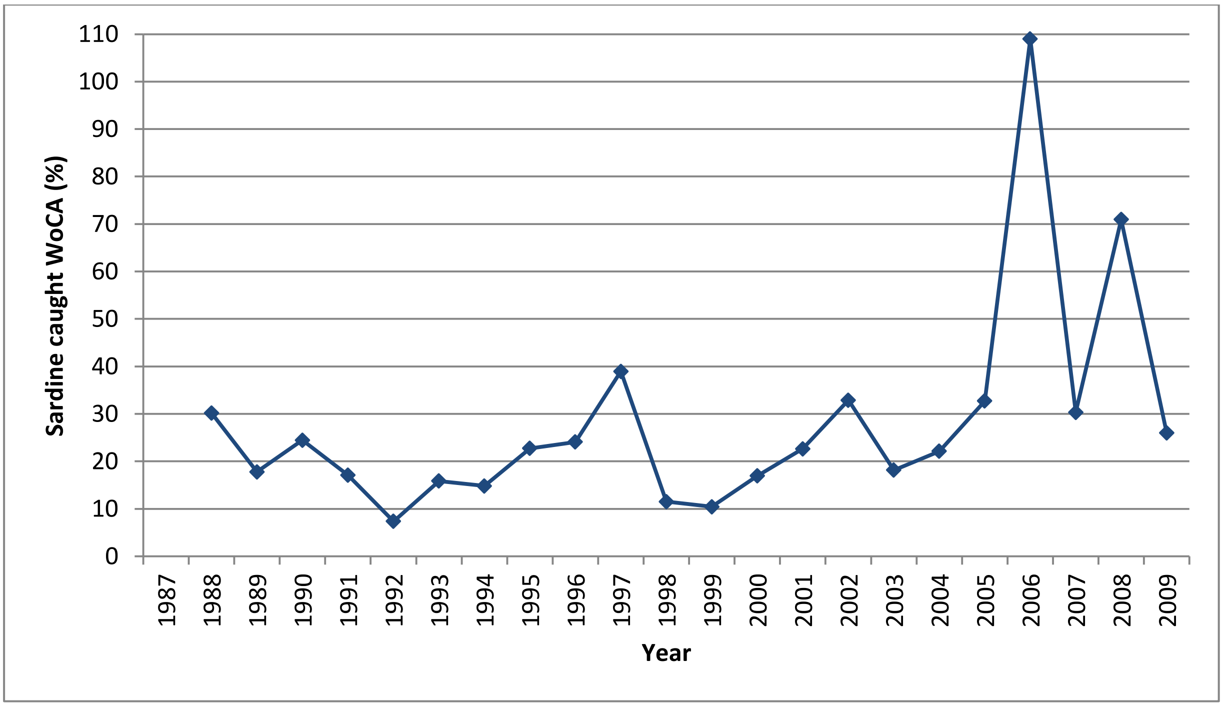


Figure 3.8: The percentage of sardine caught west of Cape Agulhas (WoCA) in the total population situated in that area in November of the previous year.

Ratio of large sardine in the sardine-directed catch west of Cape Agulhas

Managing the sardine-directed fishery sustainably requires that there is a sufficient proportion of large, sexually mature sardine remaining in the population after fishing each year. Although fishing has followed the shift in sardine biomass, fishing pressure is still high on the west coast (Figure 3.8). To maintain a stable spawner stock biomass (SSB), one of the key aims of fishery management, is to ensure that there are sufficient numbers of adult sardine in the population. Maintaining a SSB on the west coast will likely favour that recruitment. While there is currently no spatially explicit management of the fishery, managing the sardine-directed fishery responsibly against collapse requires that there is proportion of large sardine remaining in the population after fishing each year. Monitoring the removal of large sardine from the population can be done by ensuring that fishing takes into account the distribution of adult sardine. This may be able to provide an early warning system highlighting when catch of large sardine in a particular region exceeds the amount of large sardine in the population.

Large sardine are defined as adult (sexually mature) sardine in the population as of November each year. From 1987 to 1996 a standard annual cut-off length of 15.5cm was used to differentiate between immature and mature fish, but since then cut-off lengths have been determined annually from modal length analysis of acoustically weighted length weight frequencies derived from annual sardine recruit surveys (Coetzee, 2006, Coetzee and Merkle, 2007).

Commercial catch data, separated for the areas EoCA and WoCA provided estimates of total catch and length frequencies. Biomass estimates for sardine EoCA and WoCA are derived from the hydroacoustic SSB surveys conducted by DAFF in November each year. The length frequencies of sardine caught and sardine biomass were converted to mass (in tons) for each length class using a length/mass relationship by van der Lingen et al. (2006).

The proportion by mass of large sardine caught WoCA was calculated by the mass of large sardine caught WoCA to the total sardine biomass caught WoCA in the same year (equation 3.6, below).

$$Proportion\ of\ large\ sardine\ caught\ WoCA = \frac{Large\ sardine\ caught\ WoCA\ (t)}{Total\ sardine\ caught\ WoCA\ (t)} \tag{3.6}$$

The proportion of large sardine in the population WoCA was calculated as the mass of large sardine in the population WoCA to the total sardine biomass in the situated WoCA (equation 2.7).

$$Proportion\ of\ large\ sardine\ in\ the\ sardine\ population\ WoCA = \frac{Large\ sardine\ in\ the\ population\ WoCA\ (t)}{Total\ sardine\ in\ the\ population\ WoCA\ (t)} \tag{3.7}$$

The resulting ratio, presented by equation 2.8 describes the impact of fishing on large sardine found WoCA.

$$Ratio\ of\ large\ sardine\ caught\ WoCA = \frac{Proportion\ \ of\ large\ sardine\ caught\ WoCA\ (t)(eq. 3.6)}{Proportion\ of\ large\ sardine\ in\ the\ population\ WoCA\ (t)\ (eq. 3.7)} \tag{3.8}$$

The proportion of large sardine in the sardine population situated WoCA and the proportion of large sardine caught WoCA each year are shown in Figure 3.9. The proportion of large sardine in the sardine population situated WoCA was variable throughout the time series, ranging from 25% in 1991 to 95% in 2008. Decreases in the proportion of large sardine in the population WoCA can be attributed to strong recruitment over those periods. The decline in the mass of large sardine caught WoCA in 1999, 2000, 2003 and 2006 are matched, albeit to different degrees to the mass of large sardine in the population situated WoCA.

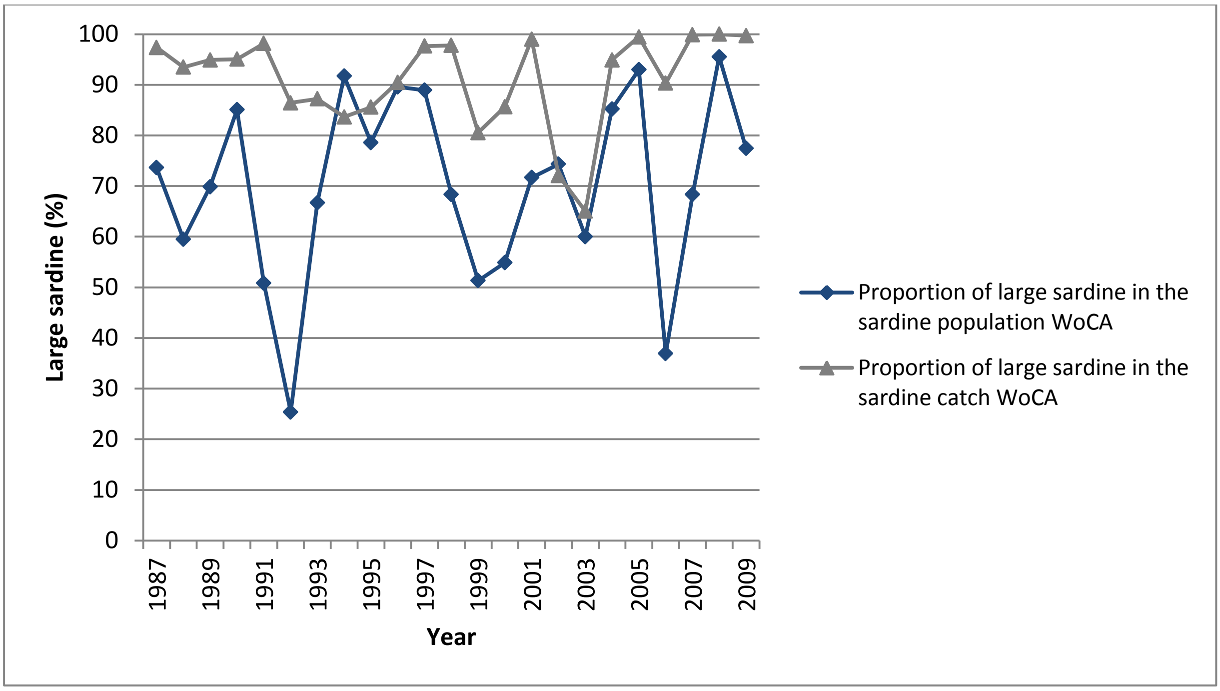


Figure 3.9: The percentage catch of large sardine caught west of Cape Agulhas (WoCA) and the percentage of large sardine in the total population situated in that area.

The resulting ratio of large sardine caught WoCA is presented in Figure 3.10, note the cut-off lengths to distinguish adult sardine from recruits vary annually from 1996. Prior to 1996 a standard annual cut-off length of 15.5cm was observed, since then cut-off lengths have been determined annually from modal length analysis of acoustically weighted length weight frequencies derived from annual sardine recruit surveys (Coetzee, 2006, Coetzee and Merkle, 2007). A ratio greater than one indicates that too many large sardine are being removed from the area WoCA, which may flag possible problems for spawners in the future and has implications on the SSB and recruitment in subsequent years. Spatially disproportionate fishing on large sardine was high during the late 1980s and early 1990s and in the early 2000s (Figure 3.10). The peak in ratio of large sardine caught in 2007 may be attributable to the drastic decline in biomass from 2005 and the slower response of catch allocation to match the decrease in available biomass, which meant that in 2007 the exploitation rate was very high due to high fishing mortality.

Stakeholders raised concern over applying a cut-off definition of large sardine from modal length analysis from the May recruitment survey, suggesting that not all sardine that are classified as spawning stock should be considered large. Alternative cut-off lengths of 16cm and 18cm were examined as potential definitions for large sardine. These standard cut-off lengths showed relatively different results, from discussions held with sardine biology experts it was agreed that the annually varying cut-off lengths used are the most appropriate to reflect the biological dynamics of sardine in South Africa (C.D. van der Lingen, Branch Fisheries, DAFF, pers. comm.).

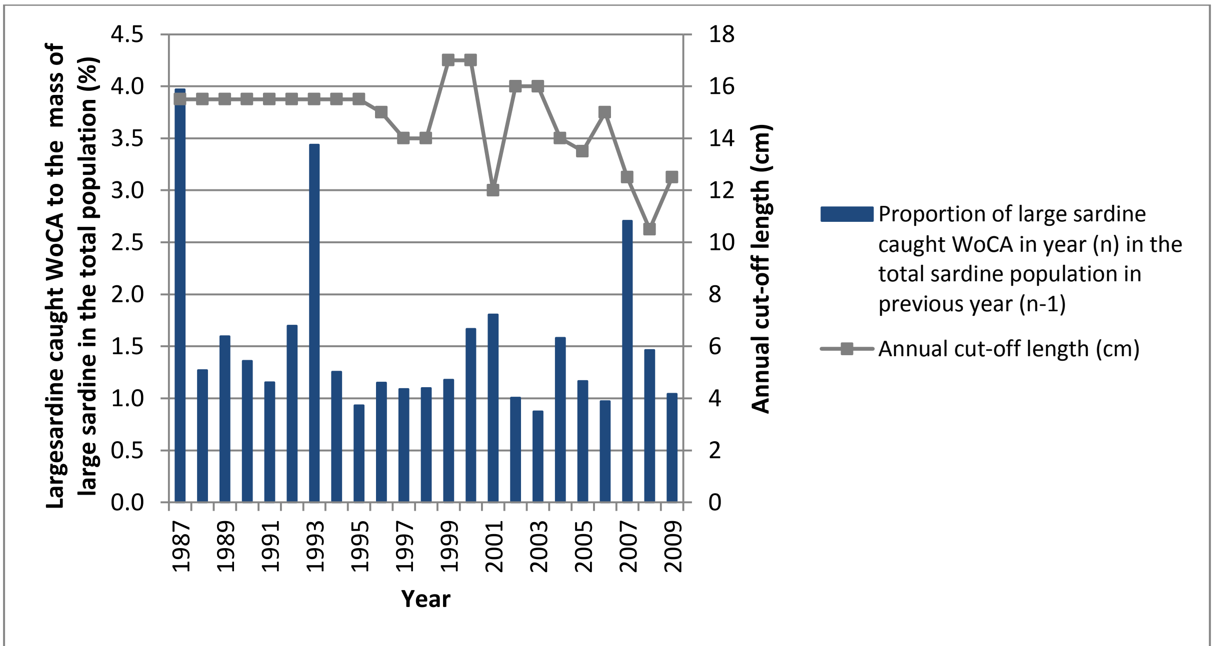


Figure 3.10: The percentage catch by mass of large sardine situated west of Cape Agulhas (WoCA) to the percentage biomass of large sardine situated in that area in November of the previous year.

1^+ Spawner stock biomass

To maintain the target stock in a highly productive state an indicator of the abundance of the target species is required, with periods of high productivity occurring when the sardine biomass increases despite ongoing fishing on the resource (Shannon et al., 2006). Sardine biomass provides a good indication of the state of the target resource, with a high biomass indicative of more fish being available for exploitation by the fishery. Spawner stock biomass (SSB) is an indicator used in single stock assessments, and reflects the total mass of the sardine in a population that are old enough to spawn. A model predicted 1^+ Spawner stock biomass (1^+SSB) is used to develop the OMP for the small pelagic fishery and to set the annual TAC for the sardine-directed fishery. This indicator is calculated from the stock assessment models, presently in use, the methodology for which is documented by de Moor and Butterworth (2008).

The stock assessment model is currently under revision (2011) and as such no new 1^+SSB data has been produced; this indicator therefore relies on previous assessment outputs for the period 1987-2006 (Figure 3.11). To update the time series to 2009 the percentage difference between the acoustically estimated SSB and model predicted 1^+SSB was calculated and averaged across the given time period (Figure 3.11). The average difference was then added to the acoustically estimated SSB values, which are estimated in November each year and provide a snapshot of SSB in population, to provide an estimate of model predicted 1^+SSB for 2007-2009. Acoustically estimated SSB consistently underestimates 1^+SSB in the population. The period 1991-1994 is indicative of this, as it was a period of stable biomass with high productivity (van der Lingen et al., 2006) and strong recruitment resulting in a recovery from a period of low biomass and a subsequent increase in biomass in following years (de Moor, MARAM, UCT, pers. comm.). The OMP-08 uses the probability of the sardine population size falling below the average 1991-1994 biomass estimates as a risk definition against which to test the model (de Moor and Butterworth, 2008; see box in Figure 3.11).

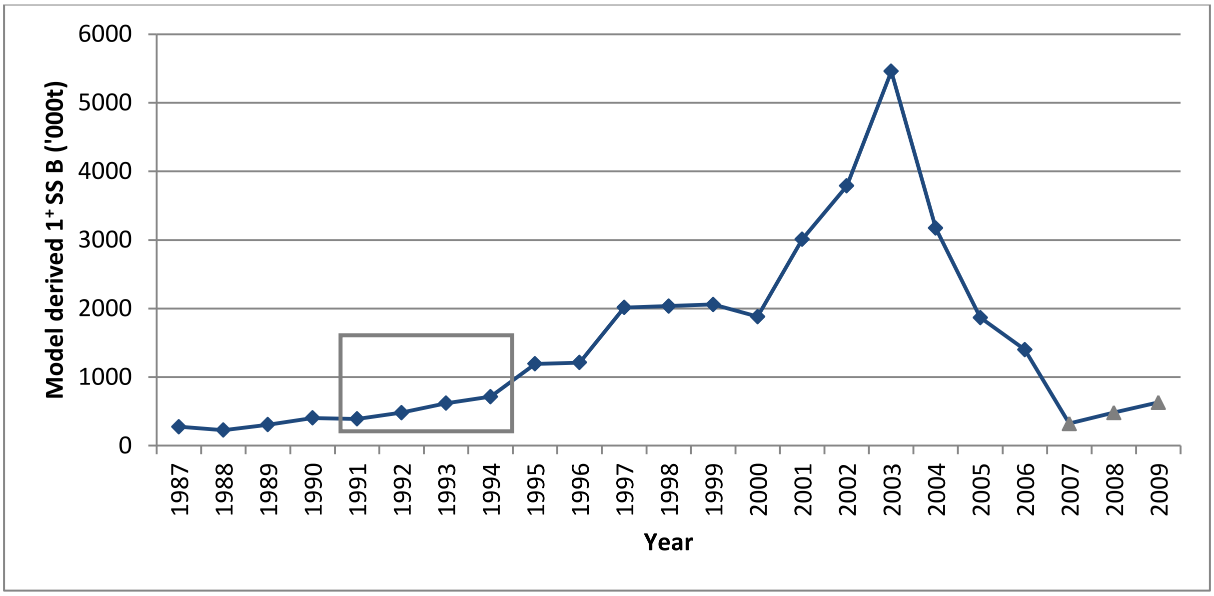


Figure 3.11: Annual model-predicted sardine 1$^+$ Sardine Stock Biomass (1$^+$SSB) ('000t). The grey box indicates the period of risk baseline for the OMP-08 (November 1991-November 1994).

This indicator is considered more appropriate than acoustically estimated SSB by fishery scientists involved in the stock assessment process. While the methodology used to predict 1$^+$SSB in the stock assessment model may be difficult to interpret by a non-expert, this indicator addresses some of the criticisms of relying too heavily on a snap shot view of the population as provided by the November SSB surveys. Model outputs also account for the sardine caught, which surveys cannot do.

<u>Relative weight</u>

The condition of the target species is a measure of the physical health of the population. The resource condition may indicate years of favourable environmental conditions, resulting in enough food for the fish, and fatter fish in the population or alternatively may indicate poor environmental conditions, where many of the fish in the population are thin (Ogle, 2010). Three commonly applied measures of condition include condition factor, relative condition factor and relative weight.

Ndjaula et al. (2013) calculated an annual sardine relative weight for each year since 1953 using the expression:

$$Relative\ weight\ (Wr) = \frac{W}{Ws} X\ 100 \tag{3.9}$$

Where W is the observed weight and Ws is the standard weight for a fish of the same length, calculated from a length-weight relationship to predict the 75th percentile weight (Ogle, 2010, Ndjaula et al., 2013). The overall condition of the sardine population is calculated by averaging the condition of all fish in the sample (Ndjaula et al., 2013).

Figure 3.12 presents the relative weight of sardine for the time period 1987-2009. This indicator shows that the relative weight of the sardine population has been declining over the period investigated. A slight peak in relative weight occurred in the early 1990s, a period of known high productivity of the population, since then sardine, however, have become significantly less ‘plump’, a possible indication that productivity of sardine is low .

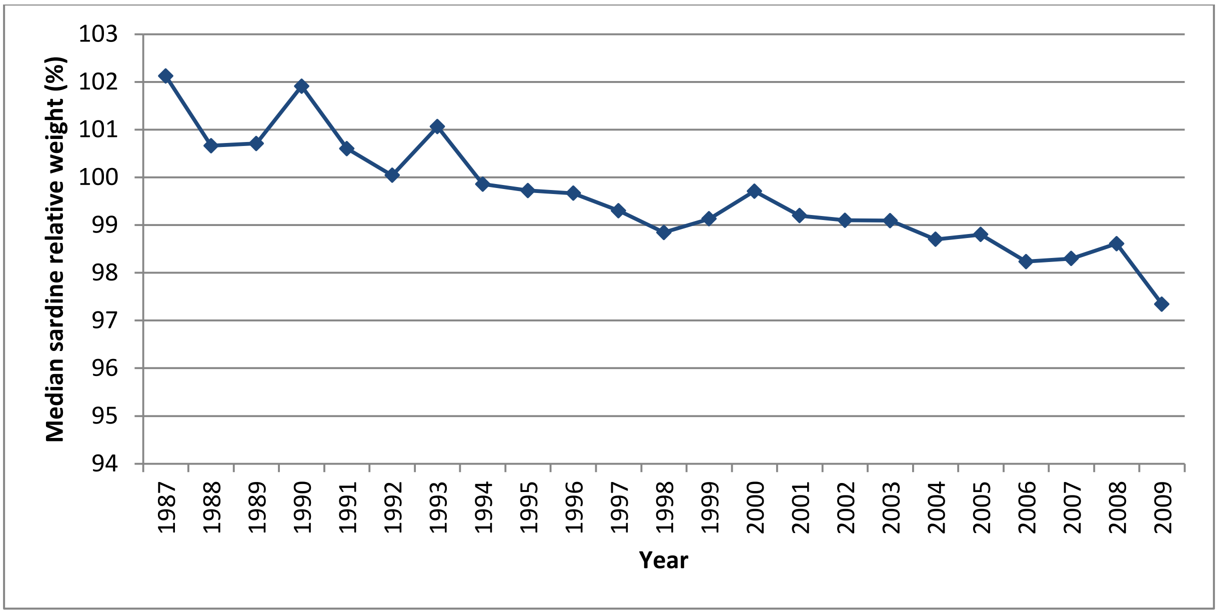


Figure 3.12: Median sardine relative weight calculated annually to show temporal change in sardine condition.

Annual trends in condition factor for the South African sardine have been presented previously (van der Lingen et al*.,* 2006). Condition factor, length at maturity and standardised gonad mass of sardine indicated a density-dependence in the sardine, with condition factor declining with increased sardine biomass (van der Lingen et al., 2006). Condition factor was been shown to be a useful indicator for monitoring changes in sardine productivity over time, but the time series has not been updated since publication in 2006 (van der Lingen et al., 2006). In addition, Ogle (2010) draws attention to the difficulties of using condition factor as a measure of overall population condition. Condition factor assumes an isometric growth, but most fish stocks, including sardine, do not exhibit isometric growth, resulting in trends in condition factor differing in fish of different size classes (Ogle, 2010).

Relative weight is suggested as a more appropriate measure of sardine condition (Ogle, 2010, Ndjaula, et al., 2013). While previous research on sardine condition have used condition factor (der Lingen et al., 2006), this new method is considered a more suitable indicator in the context of EAF implementation in the sardine fishery.

Maintain a forage base for dependent seabirds

Fisheries may negatively affect predator populations through competition for shared prey (Crawford et al., 2008, Cury et al., 2011). Seabirds, as central place foragers, are particularly reliant on the availability of prey during their breeding seasons, as they need to source adequate supplies of food within a reasonable distance of breeding colonies (Crawford et al., 2008, Oakes et al., 2009, Sherley et al., 2013, Robinson, 2014). Localised depletion of prey stocks may seriously impact the health of seabirds during breeding seasons (Crawford et al., 2006, 2008), and as has been shown in a global context that the depletion of fish stocks are having as serious an impact on seabird populations worldwide (Cury et al., 2011).

The African penguin (*Spheniscus demersus*), Cape cormorant (*Phalacrocorax capensis*), Swift tern (*Sterna bergii*) and Cape gannet (*Morus capensis*) are four species of seabird endemic to the Benguela ecosystem and feed mainly on sardine and anchovy, thus dependent on a forage base of small pelagic species. It is relevant to note that it is not always possible to separate the reliance of seabird diet to sardine or small pelagic fish. The dependence of sardine or anchovy as main food varies across time, area and species (Crawford et al., 2007a, Crawford et al., 2007b, Crawford et al., 2008, Crawford, 2009, Okes et al., 2009, Pichegru et al., 2009, Sherley et al., 2013) but a decline in the availability of sardine as prey will have an adverse effect on these species (Crawford et al., 2008, Robinson, 2014). Indicators of seabird condition relating to the availability of sardine and anchovy have been identified for these four species.

Condition of African penguins on western islands

The breeding colonies of African penguins on the west coast of South Africa have been monitored extensively for several decades, resulting in a long time series of data on breeding numbers, reproductive success, moulting, survival and diet. In recent years African penguin numbers have declined drastically and they are now classified as Endangered on the IUCN red data list (Crawford, et al., 2011, Sherley et al., 2013). The dramatic decrease in penguin population numbers on the west coast has been attributed to the decline in prey availability as a result of the eastward shift in sardine biomass since the mid-2000s (Crawford et al., 2008, 2011, Sherley et al., 2013). The limited forage range of African penguins, about 20-40km from a colony during the breeding season, makes this species very vulnerable to localised depletion of prey species (Crawford et al., 2008, 2011).

The number of breeding pairs of African penguin populations WoCA and EoCA were identified as appropriate indicators for the objective of '*Maintaining African penguin populations in good nutritional condition*'.

An additional indicator, a composite index of the health of African penguins in the Western Cape, was also identified and developed. The African penguin health index was derived from Underhill and Crawford's (2005) seabird health index, using regularly monitored indicators of penguin health. Subsequently, however, discussions on the re-analysis of penguin monitoring data showing the decoupling of local and global prey availability for African penguins (later published in Sherley et al., 2013) left uncertainty in the validity of the application of a composite index of African penguin health. A meeting with a group of seabird experts was held in October 2012 to discuss, in light of data re-visions, what indicator should be used in the knowledge-based tool. This group of experts agreed that a simpler, but more representative indicator (the number of breeding pairs in the Western Cape) was a more appropriate indicator for the condition of African penguins.

Breeding pairs of African penguins in the Western Cape

The number of breeding pairs of African penguins on 12[1] islands across the Western Cape has been monitored regularly for more than two decades; regular nest counts provide a measure of breeding pairs (Crawford et al., 2011, Sherley et al., 2013). Figure 3.13 presents the number of breeding pairs ('000) of penguins WoCA for the period 1987-2009. African penguin populations in South Africa showed some

[1]Lamberts Bay, Malgas Island, Marcus Island, Jutten Island, Vondeling Island, Dassen Island, Robben Island, Boulders, Seal Island, Dyer Island, Geyser Island and DeHoop

recovery in the mid-1990s but then suffered a collapse from approx. 35 000 breeding pairs over 2001-2005 period to 11 000 pairs in 2009. This is the lowest level of penguin numbers recorded and resulted in a reclassification of the IUCN Red list to from Threatened to Endangered (Crawford et al., 2011).

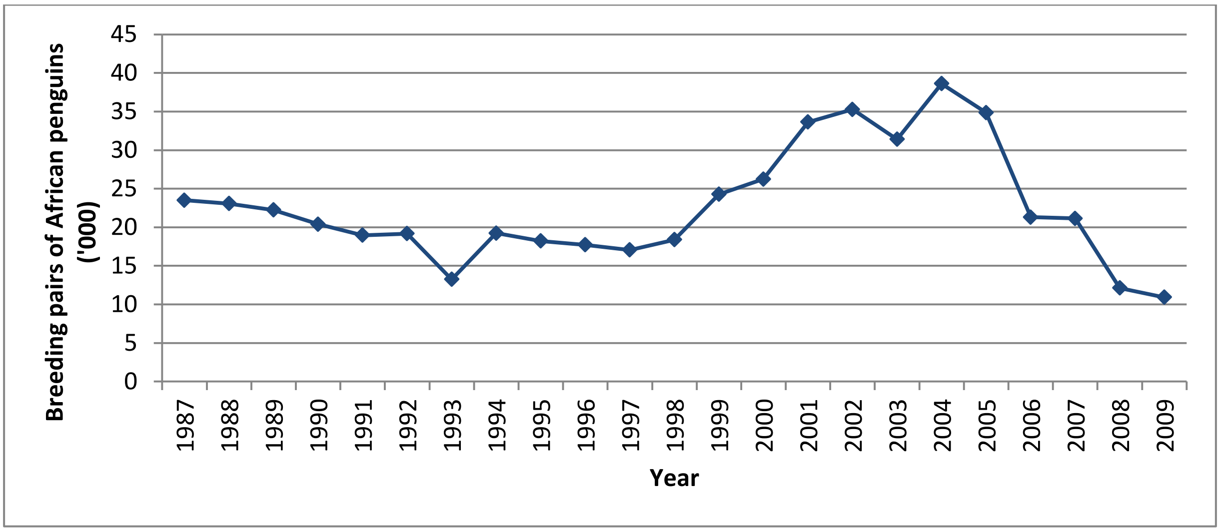


Figure 3.13: Breeding pairs of African penguins in the Western Cape.

Condition of African penguins on eastern islands

The number of breeding pairs of African penguins is used as an indicator of penguin condition on the Eastern Cape islands. Monitoring programmes on six islands[2] provide counts of nests of African penguins, which are made once or twice a year on each island and are used to estimate the number of breeding pairs (Crawford et al., 2011, Sherley et al., 2013).

[2] Jahleel, Brenton, St Croix, Seal, Stag and Bird Islands

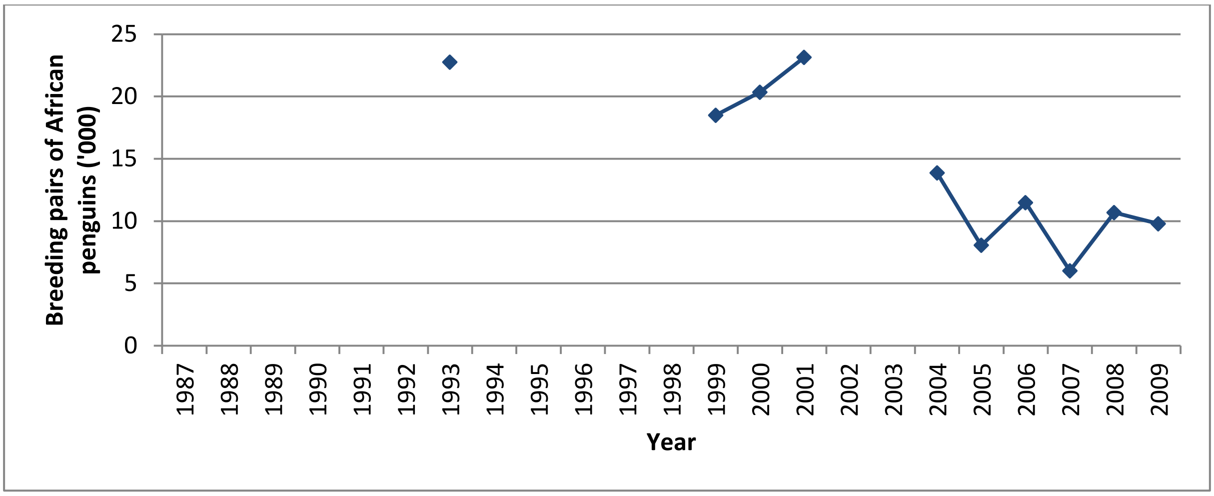


Figure 3.14: Breeding pairs of African penguins on islands in the Eastern Cape. This time series is incomplete due to logistical and cost constraints in monitoring African penguins in this area.

Figure 3.14 presents the time series of breeding pairs of African penguins on islands in the Eastern Cape. It is not a complete time series; the lack of data in some years is the result of poor and inconsistent monitoring of penguin populations in this area. Logistical and cost constraints in the past resulted in only one or two of the seven Eastern Cape islands being monitored each year. However, since 2003 concerted research effort has resulted in an improved time series of breeding pairs of African penguins in the Eastern Cape. Figure 3.14 shows a decline in penguin breeding on all islands in the Eastern Cape in the last few years. Penguin populations numbers peaked in the early 2000s and have experienced a decrease ever since, this is despite the increased availability of sardine as a result of the eastward shift of small pelagic biomass since the mid-2000s. African penguins on the eastern islands were shown to be less affected by a shift in sardine availability than penguins breeding on islands in the Western Cape (Crawford et al., 2011).

Condition of other seabirds

Indicators of the condition of Cape cormorant, Swift tern and Cape gannet populations were identified. The number of breeding pairs is used as an indicator of the condition of Cape Cormorant and Swift tern while the area occupied by Cape gannets is used as an indicator of gannet condition. The number of breeding pairs of

Cape cormorant at six localities in the Western Cape is estimated annually (Crawford et al., 2007a). The number of breeding pairs of Swift terns in the Western Cape is also monitored annually. The methodology for estimating these counts is presented by Crawford (2003, 2009). The area in hectares occupied by breeding Cape gannets is estimated from aerial photographs taken of the breeding colonies each year (Crawford et al., 2007b).

Cape cormorants breed at six localities in the Western Cape and a combined estimate of breeding pairs in the Western Cape is presented in Figure 3.15. The number of breeding pairs was high but variable initially followed by a period of low and stable numbers from 1993 onwards. Each breeding colony shows different trends in breeding numbers, however an overall long-term decrease in the number of breeding pairs has been detected from late 1970s (Lambert's Bay) and early to mid-1990s at Malgas, Jutten, Vondeling and Dassen Islands. This decline is thought to be attributed to a number of factors including avian cholera, predation by Cape fur seals (*Arctocephalus pusillus*) and great white pelicans (*Pelecanus onocrotalus*) and the eastward shift in sardine which decreased the availability of sardine to seabirds breeding on islands WoCA (Crawford et al., 2007a). Numbers of breeding pairs at Robben Island have increased, but this is due to the erection of a breeding platform adjacent to the island in 2003. Cape cormorants do not breed in large numbers EoCA.

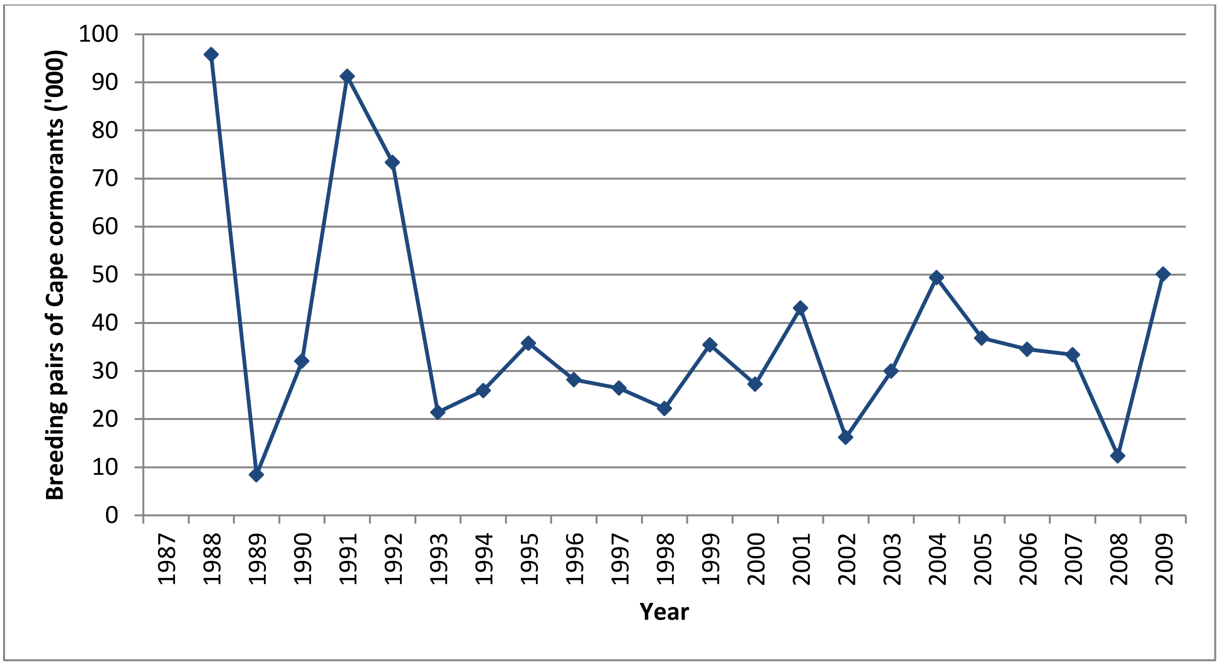


Figure 3.15: Breeding pairs of Cape Cormorants at six breeding localities within the Western Cape.

The number of breeding pairs of Swift tern in the Western Cape has increased significantly since the early 1990s (Figure 3.16). This increase has been attributed to immigration, good recruitment to the mature population and increased number of mature birds breeding (Crawford, 2009). In addition, the increase in numbers breeding has benefited from increased abundance of prey in the late 1990s. Up until 2000, breeding numbers of Swift tern in Western Cape were significantly related to biomass of sardine (Crawford, 2009). Crawford (2009) found a significant relationship between numbers of Swift tern breeding in the Western Cape and biomass of sardine as well as combined biomass of sardine and anchovy and also a significant correlation between Swift tern breeding numbers and the proportion of sardine and anchovy EoCA (Crawford, 2009). Swift terns have a longer foraging range than other endemic seabirds and after breeding disperse eastwards towards KwaZulu Natal. In addition, a change in the distribution of breeding localities, from the north to the south western Cape has helped mitigate the effect of the eastward shift of small pelagic fish.

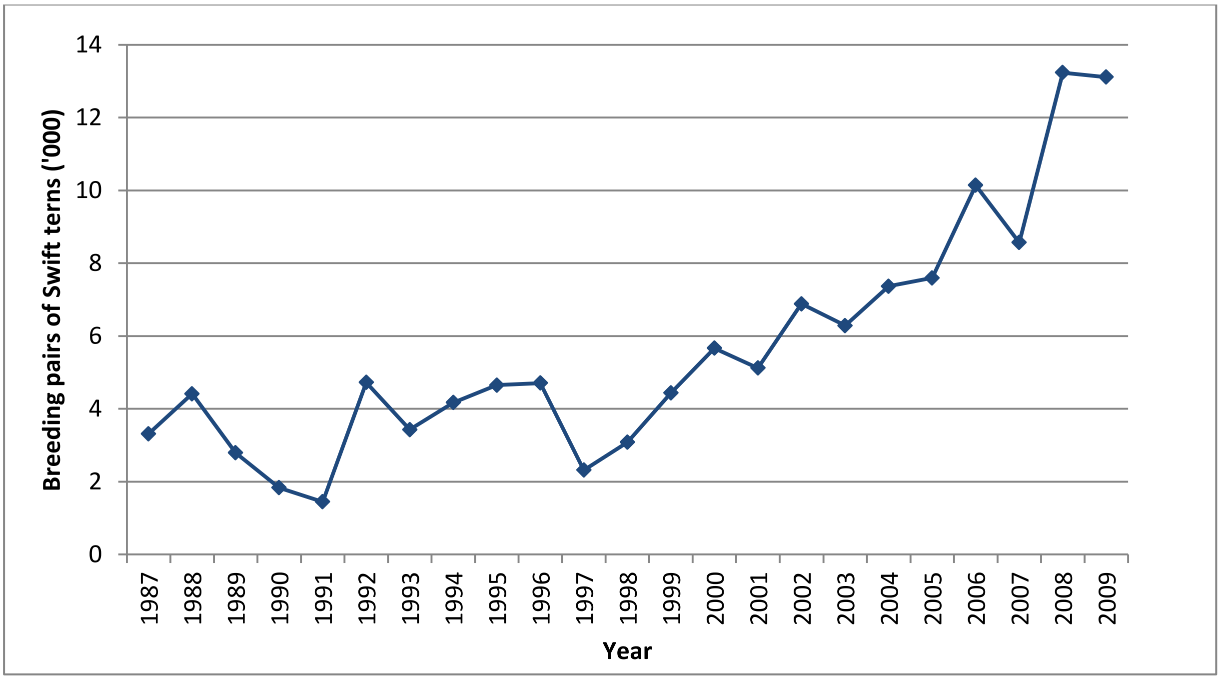


Figure 3.16: Breeding pairs of Swift Terns at all breeding localities.

Cape gannets breed at three localities in South Africa (Bird Island and Malgas Island in the Western Cape and Bird Island in Algoa Bay, Eastern Cape). Area (in hectares) occupied by breeding Cape gannets was used as an indicator of breeding colony size and in this context used to indicate the condition of Cape gannets, the number of breeding pairs had not been updated for the most recent period in the time series and the expert consulted had more confidence in this indicator. Breeding colonies of Cape Gannets in South Africa were relatively stable from the mid-1990s to the early 2000s, averaging 2ha. A decline in the area occupied by Cape gannets from 2002-2004 was attributed to sustained attacks by Cape fur seals which lead to the abandonment of the Bird Island breeding colony in Lamberts Bay (Crawford et al., 2007b). Sustained changes in population size and distribution has been attributed to changes in prey availability, with many Cape gannet moving eastwards following the sardine shift in the mid-2000s (Crawford et al., 2007b).

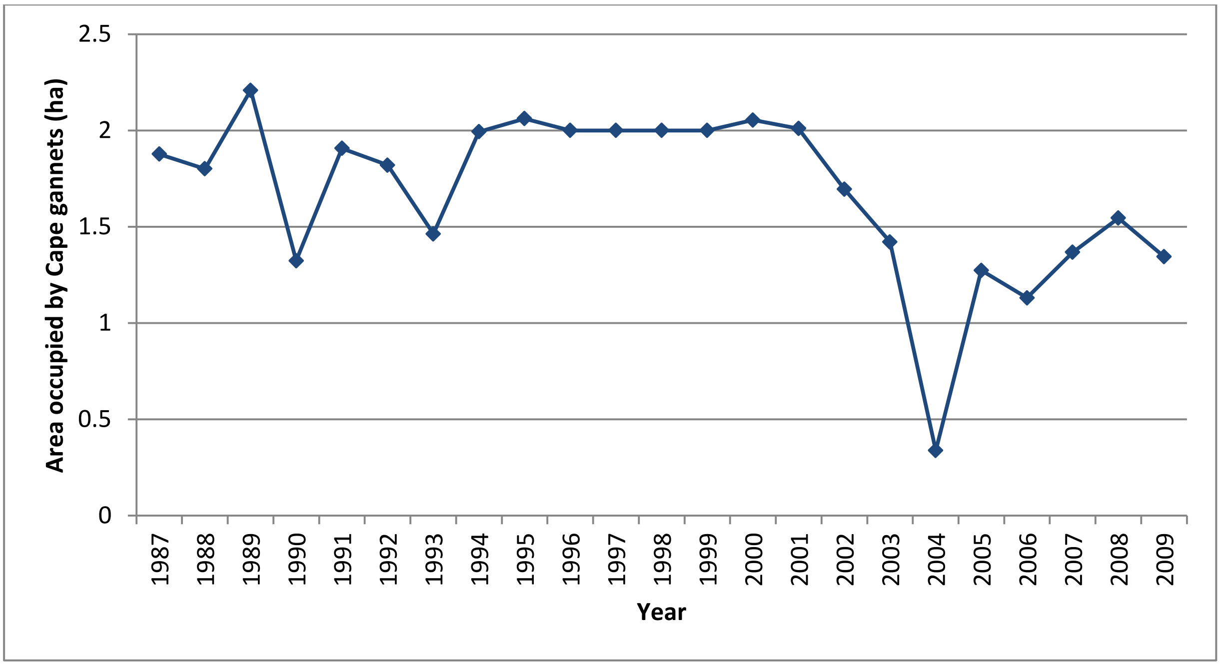


Figure 3.17: The area, in hectares, occupied by breeding pairs of Cape Gannets in the Western Cape.

3.5. 'Switched off' objectives: Objectives not linked to indicators

While efforts were made to identify indicators for all objectives in the hierarchy this was not always possible and some of the objectives are 'switched off' in this assessment. These were not included in the final discussion on indicator selection. The reasons for 'switching off' these objectives and future research opportunities relating to developing indicators for these objectives are discussed below.

<u>Optimise sardine mortality – minimise dumping</u>

Discarding, the dumping of incidental or unwanted catch at sea, is usually difficult if not impossible to quantify as it is illegal and unreported. The discard of sardine too small for canning is highlighted as a particular issue in the sardine-directed fishery. In response to concerns raised over dumping and bycatch an observer programme was introduced in the small pelagic fleets. General Linear Model (GLM) analyses of catch per hour data for the sardine fishery have been run to determine 'observer effects' on landings of sardine (Sobhlaba et al., 2011). The results showed significant differences in catch rates of vessels with observers on board to those without observers present.

The GLM showed promise as an indicator for discard by the sardine-directed fishery. However, when the GLM was updated in July 2011 and new data was included in the model, the trend over time that resulted out of this could not be explained by the fishery scientists. The confusion over the results and a call to revise the methodology and observer data by the SWG-PEL has resulted in this indicator and associated objective being switched off in the current process.

<u>Minimise bycatch in the sardine fishery</u>

Bycatch in the sardine-directed fishery is relatively minimal at present, with small quantities of redeye round herring and juvenile horse mackerel currently caught as bycatch. The impact of bycatch of these species is not significant as there was no dedicated fishery for redeye or horse mackerel in South Africa at the time and therefore no indicators for objectives have been identified. Plans to develop a horse mackerel fishery are currently under review in DAFF if this fishery is opened the impact of bycatch of juvenile horse mackerel to recruitment in the horse mackerel population by the sardine fishery may become important. A small mid-water trawl fishery for redeye based on a Precautionary Upper Catch Limit is in operation out of Mossel Bay, although bycatch is not currently a concern in this fishery. This objective is switched off in the current assessment but is kept in the objectives' hierarchy for future consideration of the consequences of bycatch by the sardine fishery.

<u>Minimise disturbance of seabirds by the sardine fishery</u>

Four seabird species in the southern Benguela ecosystem are dependent on sardine and anchovy as food. These species are limited in their forage range during the breeding season, having to return to nests to feed chicks. African penguins have a forage range of 20-40km, while Cape cormorants, Swift terns and Cape gannets have a wider forage range, up to 80km. The impact of localised fishing pressure on the availability of sardine and anchovy to breeding seabirds in South Africa is well documented (Crawford et al., 2006, 2007b, 2008, 2011, Oakes et al., 2009). Potential indicators for this objective relate to the number of fishing vessels passing in the vicinity of breeding colonies. DAFF has documents of spatial records (for example, from 2011 GPS positions of catche have been recorded) of each catch of sardine and anchovy by fishing vessels. These datasets are not fully analysed but have the potential to develop into an indicator of fishing pressure around breeding colonies of seabirds. Additional information on the effects of localised fishing on African penguins will be available once the results of experimental closures of fishing grounds around islands housing breeding colonies of African penguins in the Western and Eastern Cape are published (Weller et al., 2014, Sherley et al., submitted).

In a recent paper by Weller et al. (2014), a systems dynamics model of the African penguin colony on Robben Island suggested that the effect of oiling from shipping vessels and shipwrecks close to Robben Island significantly affects penguin breeding colonies. While not currently studied, the impact of passing boats from recreational and tourist activities may disturb seabirds at the island-based breeding colonies, for example extensive shark-cage and whale watching activities occur around Dassen Island and large volumes of tourist and shipping traffic occur within the penguin forage range around Robben Island. Understanding the impact of this disturbance on seabirds may contribute to developing an indicator for this objective, but was not considered in the current process.

<u>Maintain a forage base for other dependent predators</u>

Sardine are an important prey species for several top predators, including hakes (*Merluccius paradoxus and M. capensis)*, snoek (*Thyrsites atun)* and other linefish, Cape fur seals (*Arctocephalus pusillus*), whales and cetaceans and a number of shark species. The removal of forage fish through existing fisheries practices may have a negative effect on dependent predators, in particular species which are bound by land-based breeding colonies such as seabirds and seals.

The Cape fur seal is a well-known predator of sardine and anchovy in the Benguela ecosystem. Changes in Cape fur seal distribution and a decline in population numbers along the Namibian coastline has been attributed to the collapse of the sardine in the northern Benguela. Similar changes in distribution, seal pup survival and population numbers could occur in South Africa (Kirkman, 2010). Monitoring of seal populations, pup counts and diet analyses have been conducted sporadically in the southern Benguela off South Africa (Kirkman, 2010), but the data collected are unfortunately too inconsistent to currently be developed into an indicator of seal health in relation to sardine availability. Investment into consistent monitoring of seal pup numbers, weight and condition and seal diets started in 2010; these data have the potential to be used as indicators of seal health (S. Kirkman, Oceans and Coasts, Department of Environmental Affairs, pers. comm.).

Hakes, snoek and other linefish are known predators of small pelagic fish, and the mainstay of other commercial fisheries. No evidence could be found to link linefish, to a dependence on sardine in their diet (S. Kerwath, Branch Fisheries, DAFF, pers. comm.). Linefish tend to be migratory and have a varied diet, of which small pelagic fish contribute to in varying degrees. The monitoring of linefish species is limited, constrained to the few commercially caught species and even this is irregular and inconsistent (Smale, 1992, Winker, 2013). The influence of changing abundances of prey would most affect species with a narrow forage range, as most linefish are relatively sedentary in comparison to small pelagic species, developing an indicator of linefish condition relating to the availability of sardine would be hugely helpful for EAF management. Regular monitoring of diet, age, size and lipid content, amongst other measures needs to be undertaken to help develop a suitable indicator for the health of dependent fish species.

A diet analysis of snoek was conducted by McQueen and Griffiths (2004). The results of their research suggest that sardine and anchovy contribute significantly to the diet of snoek, but the relative contribution varies in terms of area, offshore or inshore and age of the snoek, whether juvenile or adult (Griffiths et al., 2002). However, the methodology of data collection has been questioned by Griffiths et al. (2002). For snoek diet to be a useful indicator to measure the influence of sardine availability on the condition of snoek in the southern Benguela ecosystem more intensive and consistent sampling would be required, this may occur in the future, but is not well developed enough at present.

The dusky dolphin (*Lagenrhynchus obscurus*) and Brydes whale (*Balenoptera edeni*) have been suggested by cetacean experts at Bayworld to be the most reliant species on small pelagic fish in their diet. Unfortunately, very few studies have been conducted on the diet of these species, and analyses of stomach contents are usually only done when a species is found washed up on a beach or caught in the KwaZulu Natal shark nets. The only recent diet analysis on long-beaked common dolphins (*Delphinus capensis*) has been conducted by Ambrose et al. (2013). Their research indicated that dolphins caught in shark nets off the KwaZulu Natal coastline had consumed mainly sardine and anchovy (Ambrose et al., 2013). However, many of the dolphins were caught during the sardine run and the geographic locality of these individuals is beyond the direct influence of the sardine-directed fishery, which operates only to just east of Port Alfred in the Eastern Cape. This information is therefore not applicable in the context of the southern Benguela ecosystem.

It is not likely that an appropriate indicator of cetacean condition relating to the availability of sardine will be available in the future, as monitoring of dolphins and whales is difficult and may be met with opposition by animal rights activists as many of these species are listed on the IUCN red data list, and draw important revenue through tourism for South Africa. To discard this objective from the list of management objectives for an EAF in the sardine-directed fishery, however, would be significant. While it is perhaps difficult to monitor these species and quantify the influence of small pelagic fish to their diet, there is little contest that overfishing will adversely impact these species.

3.6. Discussion and conclusion

Indicators are regularly used to track and evaluate the effectiveness of EAF implementation (Garcia et al., 2000, FAO, 2003, Rice, 2003, Jennings, 2005). A suite of ecological indicators has been identified and described in this chapter, with each indicator being linked to a management objective for the ecological well-being dimension of EAF in the sardine fishery. The indicators were developed through consultation with stakeholders and represent the most appropriate indicator for the objective given the best available scientific information, expert knowledge and time constraints.

A solid scientific base has been developed for EAF in the small pelagic fishery, resulting in robust, long-term datasets which were used to inform indicator selection (for example, Fairweather et al., 2006a, 2006b, Shannon et al. 2004, 2006, 2010). Working with experts in developing the indicator suite has resulted in indicators that are based on the best available information. The experts consulted were directly involved in the relevant field, often in both the collection and analysis of the data.

The indicators selected are easily measured and represent relatively long-term data sets, and the time series show trends from 1987 to 2009. An EAF provides a broad, strategic approach for management (Shannon et al., 2010), and interpreting trends in indicators over time can help provide a context for strategic management. For example, knowing when a period of spatially proportionate fishing occurred can inform managers on what conditions they should be aiming at recreating to return to a similar period in the indicator time series. The data underlying the indicators are easily accessible through on-going monitoring programmes within DAFF and DEA or from published papers. Ensuring that the data time series are accessible helps keep the indicators relevant to management and helps in communicating the indicator to stakeholders. While the term ‘easily measured’ can be interpreted quite differently by stakeholders with different technical expertise, by describing how each indicator was compiled ensures the transparency and repeatability of the indicator development process.

Recently, indicators for ecological well-being of the South African anchovy fishery have been developed (Astor, 2014). The indicator development process in Astor's (2014) research followed the approach applied in this chapter, and complements the indicators developed for ecological well-being in the sardine fishery.

An EAF requires that stakeholders are included in management decisions (FAO, 2003, Garcia, et al., 2003, Degnbol, 2003, Degnbol and Jarre, 2004, Wilson et al., 2006). By involving stakeholders in the selection of the indicators more stakeholder buy-in to the process was achieved. Stakeholders' understanding of the issues relating to EAF in the sardine fishery is highly valuable when developing appropriate indicators. The two stakeholder meetings formed part of longer EAF-SWG and SWG-PEL meetings. The interest by and expertise of the stakeholders consulted during these meetings was considered appropriate. Most of the stakeholders have background training in natural sciences; however not all are currently working directly in research with many holding in-house positions within DAFF or DEA where positions include fieldwork or data processing. Other stakeholders are mainly research positions, the balance of this means that stakeholders will have different perspectives that would be captured during their input in the meeting.

The stakeholders consulted generally agreed with the experts on the selection of indicators. Some discussion over the indicators of spatially disproportionate fishing and relative weight occurred during the stakeholder meetings. These indicators were new to the stakeholders; the indicators of spatially disproportionate fishing were developed specifically for use these objectives and the indicator of relative weight was in development at that time (Ndjaula et al., 2013). Further discussions with the stakeholders during the meetings ensured they understood the justification for using the indicator selected and consensus on the suite of indicators among the stakeholders was reached.

The objectives' hierarchy to which the indicators identified here were linked was developed prior to this research. These objectives where developed through extensive stakeholder consultation (Nel et al., 2007, Jarre et al., 2007, EAF-SWG, 2009). As a result, they were assumed to represent the stakeholder's concerns for EAF in the fishery and were not discussed during the indicator development process. Not all stakeholders consulted in this chapter were involved in setting the objectives and some expressed concern over the wording of some of the objectives. This presented some difficulty in keeping focus on the indicators during the stakeholder meetings. The wording of the objectives for spatially disproportionate fishing and SSB where eventually changed to better reflect the stakeholders' understanding of the objective. This highlighted the importance of including all stakeholders from the start of a project (Turnhout et al., 2007). While this wasn't possible, more effort was made to ensure that the stakeholders were aware of the process of objective identification and the justification for the objectives chosen for ecological well-being in the sardine fishery.

Not all of the objectives in the hierarchy could be linked to indicators. While these objectives are 'switched off' in the hierarchy, their contribution to tracking the implementation efficacy of EAF in the sardine fishery is still important. The objectives have been retained in the current objectives' hierarchy. Disregarding the impact of the sardine fishery on top predators and on bycatch species populations, for example, is contradictory to the EAF approach advocated in this thesis. Possible indicators linked to these 'switched off' objectives have been identified and are presented in section 3.4. Areas where more research or possible new research questions are required to develop indicators have been highlighted. In particular, the recent focus on improved monitoring of Cape fur seal and African penguin populations shows promise for new indicators in the next iteration of this research. An EAF requires fisheries management to address the impacts of the fishery on the wider ecosystem. Ensuring all impacts are considered, if not explicitly measured or accounted for through current research and monitoring practices has a valuable role in strategic planning for EAF implementation. These ‘switched off’ objectives identify research and knowledge gaps and may highlight where future research and monitoring efforts for EAF should be focused.

The indicators, provide valuable information against which to track the progress towards meeting the management objectives, but are not directly comparable. To interpret these indicators against each other and the management objectives, thresholds, or reference points need to be selected for them (Degnbol, 2003). In the following chapter, Chapter 4, a knowledge-based tool for assessing EAF implementation efficacy in the South African sardine fishery is developed. The knowledge-based tool provides a framework to combine indicators with objectives through the objectives’ hierarchy. Selecting threshold parameters against which to interpret and transform indicators is the first step in the knowledge-based tool development process.

Chapter 4

Building the knowledge-based tool: Thresholds, weights, expert system design and sensitivity analysis

4.1. Introduction

Various tools falling within Multi-Criteria Decision Analysis provide a formal approach that takes explicit account of multiple criteria, while effectively dealing with risk and uncertainty and allowing the combined evaluation or synthesis to be transparent and understandable to all those involved in the process (Belton and Stewart, 2002, Goodwin and Wright, 2004, Paterson et al., 2007). In Chapter 3, a suite of indicators linked to stakeholder agreed management objectives tracking progress towards EAF implementation in the South African sardine fishery were identified. As no single indicator can provide a measure of EAF efficacy, a suite of indicators is necessary to capture the complexity and multiple objectives associated with an EAF (FAO, 1999, Rochet et al., 2007, Shin et al., 2010). To do this effectively, the indicators need to be combined or synthesised in an appropriate manner to allow for meaningful interpretation and communication of results among stakeholders (FAO, 2003, Degnbol and Jarre, 2004)

This thesis aims to revise the expert system developed by Paterson et al. (2007) to track EAF implementation efficacy in the sardine fishery. Expert systems, also known as knowledge-based systems, are models that use expert knowledge to mimic the way decisions are reached by experts (Belton and Stewart, 2002). Expert systems help to make the decision processes transparent, defensible, communicable and reproducible to a wider audience (Belton and Stewart, 2002, Goodwin and Wright, 2004). Expert systems are able to combine both quantitative and qualitative information, as well as incorporate various sources of knowledge. This makes them a particularly useful tool for an EAF as this approach requires a means to deal with multiple objectives, complexity and uncertainty (Belton and Stewart, 2002, Goodwin and Wright, 2004, Paterson et al., 2007).

The knowledge-based tool developed in this chapter provides a method to structure a complex problem in a formal, transparent and documented manner, and allows for group interactions where stakeholders can be included in the tool development process. Paterson et al. (2007) focused on building stakeholder relationships rather than refining the expert system design and data underpinning the tool. This iteration of the knowledge-based tool is aimed at maintaining stakeholder interaction while ensuring that the tool is based on the best available scientific information and presents a scientifically defensible method.

4.2. Methods

The process towards developing a knowledge-based tool to track the efficacy of EAF implementation in the South African sardine fishery is described in this chapter. Figure 4.1 presents the steps followed to build the prototype knowledge-based tool. The objectives for EAF implementation were previously identified and in Chapter 3 were linked to ecological indicators forming the basis for the objectives' hierarchy used as the framework underpinning the knowledge-based tool. The first step in building the knowledge-based tool in this chapter was to identify threshold values for each indicator. Thresholds are used to transform the indicators to a common scale, against which the indicators can be compared and aggregated. A method to aggregate indicators and objectives through the hierarchy was then developed with stakeholders. Weights for each indicator and objective in the hierarchy were identified by stakeholders. A sensitivity analysis was then conducted against the indicator thresholds and weights selected. The outputs of the knowledge-based tool were then produced and presented to stakeholders.

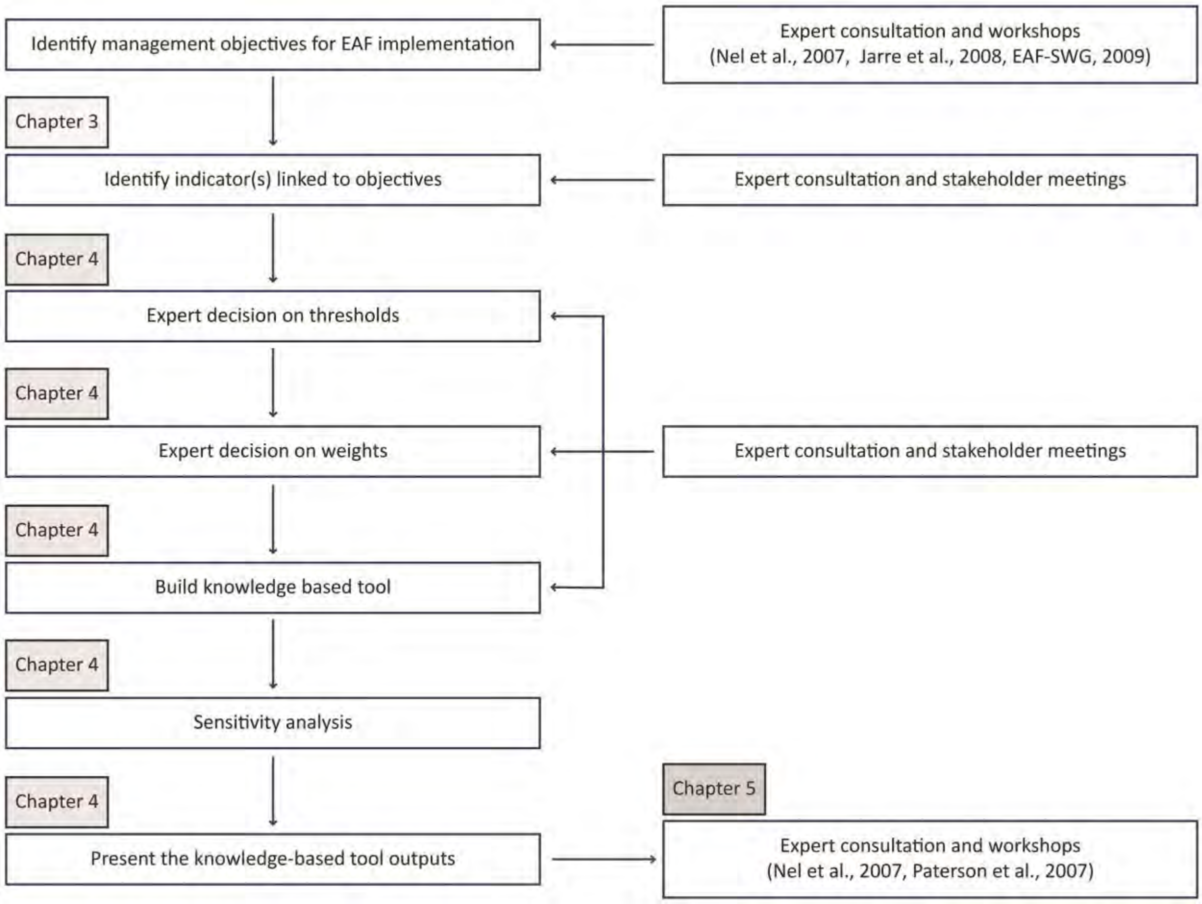


Figure 4.1: The steps followed in developing the knowledge-based tool. Chapter 4 documents the process taken in building the knowledge-based tool through expert-selection of indicator thresholds and weights, the tool built using a weighted mean summation and a sensitivity analysis conducted.

4.2.1. Selecting thresholds

The first step in developing the knowledge-based tool was to identify threshold values for each indicator in the hierarchy. These thresholds provide a reference value against which the indicators can be transformed to a common scale (Paterson et al., 2007). The same experts consulted during indicator development process in Chapter 3 where asked to identify three threshold values for each indicator (see Table 3.1 for list of experts consulted). The choice of three thresholds reflects a 'traffic light' approach (Jarre et al., 2008) describing a period when the indicator is considered to be in a good (green), okay (orange) or bad (red) state. Thresholds where identified as far as possible from published data, but if this was not available then expert knowledge was relied on to determine the indicator threshold values.

4.2.2. Transforming indicators

Transforming indicators to a common scale simplifies their interpretation and allows indicators to be compared over time. The expert-selected threshold values provided the thresholds for this transformation. A numerical transformation was chosen over a rule-based approach, in line with the method used by Paterson et al. (2007). A piecewise linear transformation was applied to transform the indicators onto common numerical scale from -1 to +1. A value of +1 indicates an objective to which the linked indicator is fulfilled, i.e. 100% true, and -1 where an objective to which an indicator linked is no fulfilled, i.e. 100% false. Zero (0) is used as a neutral or okay value in line with the interpretation used in NetWeaver (Paterson et al., 2007, www.rules-of-thumb.com), and zero is also returned if the value for a specific year is undetermined or missing. This transformation provides a continuous measure of output values rather than abrupt values, true or false values, used in crisp-logic combinations (Paterson et al., 2007). A code in the statistical software package R was developed to aid transformations of indicator values in the time series to the corresponding output values.

4.2.3. Building the knowledge-based tool: Aggregating indicators and objectives

Several methods to aggregate, or combine, indicators have been developed. Mathematical operators, such as the 'Fuzzy AND' operator used by Paterson et al. (2007), provide a defensible and transparent method to combine indicators. This method effectively deal with uncertainty, by retaining a conservative output when uncertainty is high, thus preventing the 'AND' evaluation from being overly optimistic (Reynolds, 1999). NetWeaver, the software programme used by Paterson et al. (2007), offers a number of alternative mathematical operators, such as the 'Fuzzy OR', 'Fuzzy NOT' and switch nodes (Reynolds, 1999). Simple mathematical functions such as a weighted mean are commonly used in Multi-Criteria Decision

Analysis techniques (see Belton and Stewart, 2002). This can be readily developed in MS Excel which is easily accessible and widely used. Jarre et al. (2008) compared the use of fuzzy logic to a rule-based method for combining indicators in the sardine-directed fishery and found that whilst the rule-based methods are useful as they rely on linguistic operators and are relatively intuitive for the user, this method can get clumsy when large numbers of indicators are to be evaluated. Alternative methods also include purely visual combinations of indicators in a traffic light system, such as pie diagrams or radar plots (for example, Shin and Shannon, 2009). The method selected to aggregate the indicators and objectives through the hierarchy will form the basis of the knowledge-based tool.

Stakeholder consultation

Two stakeholders meetings were held to aid the development of the knowledge-based tool in this chapter. The first meeting was held on 3 March 2011 during the regular EAF-SWG meeting (Table 4.1). The second meeting formed part of the monthly SWG-PEL meeting on 17 May 2011 (Table 4.2). At both meetings I gave a short presentation of the progress in developing the tool, as well as the indicator and threshold development. While emphasising that the indicators were not for discussion, I presented the options for aggregating the indicators and objectives. These were the 'Fuzzy AND' used by Paterson et al. (2007), a rule-based approach used by Jarre et al. (2008) and a weighted mean (for example, Gurocak et al., 1998). The most appropriate method for aggregating the indicators was the discussed with the stakeholders in both meetings. Stakeholders involved in these meetings were the members and observers of the EAF-SWG and SWG-PEL. All stakeholders have an interest in either the management of the small pelagic fishery, through their membership of the SWG-PEL or an EAF through their membership with the EAF-SWG. The stakeholder's institutional affiliation and area of expertise are listed in Tables 4.1, 4.2 and 4.3; their membership of these organisations is also represented in their holding a role in a SWG. This is considered a sufficient representative of a stakeholder's expertise and interest in the knowledge-based tool.

Feedback from these meetings suggested that, despite Paterson et al. (2007) applying this method, the use of the ‘Fuzzy AND’ and a software programme NetWeaver (which was not well known by the stakeholders) would not be the best way to aggregate indicators through the knowledge-based tool. In addition, stakeholders were unfamiliar with fuzzy set theory and would be required to ‘trust’ the underlying logic of the approach (Jarre et al., 2008) and using a more transparent approach was considered preferable by the stakeholders. The rule-based method was not considered useful by the stakeholders, as the qualitative nature of this method did not match the scientific nature of the indicators and the stakeholder expertise. The consulted stakeholders agreed that for the knowledge-based tool the application of a simpler mathematical function, namely the weighted mean calculation in MS Excel, would be the most logical and acceptable method.

Table 4.1: Stakeholders present at the EAF-SWG meeting on the 3 March 2011.

Name	Institution/ Affiliation	Area of expertise
Carl van der Lingen	DAFF	Small pelagics and EAF
Astrid Jarre	Ma-Re UCT	EAF
Lynne Shannon	Ma-Re UCT	EAF
Rob Crawford	Oceans and Coasts, DEA	Seabirds
Herman Oosthuizen	Oceans and Coasts, DEA	Top predators
Johan de Goede	DAFF	Sardines and management
Newi Amakhado	Oceans and Coasts, DEA	Seabirds
Samantha Petersen	WWF South Africa	EAF

Table 4.2: Stakeholders present at the SWG-PEL meeting on the 17 May 2011.

Name	Institution/ Affiliation	Area of expertise
Janet Coetzee	DAFF	Small pelagics
Jan van der Westhuizen	DAFF	Small pelagics
Yonela Geja	DAFF	Small pelagics
Johan de Goede	DAFF	Small pelagics
Carl van der Lingen	DAFF	Small pelagics
Sobahle Somhlaba	DAFF	Small pelagics
Nandipha Twatwa	DAFF	Small pelagics
Deon Durholtz	DAFF	Small pelagics
Carryn de Moor	MARAM UCT	Fishery stock assessment
Doug Butterworth	MARAM UCT	Fishery stock assessment
Fannie Shabangu	DAFF	Small pelagics
Mzwamadoda Phillips	DAFF	Small pelagics
Ashok Bali	DAFF	Small pelagics
Astrid Jarre	Ma-Re UCT	EAF

To define the weights to use in the knowledge-based tool a third stakeholder meeting was held with the EAF-SWG on 1 October 2011. The list of the stakeholders consulted to set weights is presented in Table 4.3. The stakeholders were shown a suite of previous weights selected at the 2007 Pringle Bay workshop (6-7 November 2007, Jarre et al., 2007). I described the justification for selecting these weights and emphasised that as the indicators underpinning the objectives and the objectives themselves had been revised since 2007 the choice of weights needed considerable revision. Stakeholders were then asked to provide their choice of weights and their justification for these selections. Each stakeholder was given a form with a table of the indicators and objectives (representing objectives' hierarchy) and asked to fill in their choice of weights for the indicators and objectives, and if possible write a short description of why they assigned the weights the way they did (see Appendix 2). For ease of communication, weights were assigned as a percentage, with each level in the hierarchy needing to add up to 100%. A final suite of weights for indicators and objectives in the knowledge-based tool was then determined from the stakeholder selected weights.

Table 4.3: List of members of the EAF-SWG who attended meeting on 1 October 2011and contributed to selecting weights to use in the tool.

Name	Institution/ Affiliation	Area of expertise
Newi Amakhado	DAFF	Seabirds
Carl van der Lingen	DAFF	Sardines and EAF
Larry Hutchings	Oceans and Coasts, DEA	Sardines
Rob Crawford	Oceans and Coasts, DEA	Seabirds
Astrid Jarre	Ma-Re UCT	EAF
Herman Oosthuizen	Oceans and Coasts, DEA	Top predators
Steve Kirkman	Oceans and Coasts, DEA	Top predators

Weighted mean

The weighted mean assumes that not all indicators and objectives are equally important, and requires that they are given a weight in the objectives' hierarchy. To calculate a weighted mean, a weight was assigned to each indicator and objective in the hierarchy. The weight selected determined the relative importance of each indicator and objective. The indicator value (x) was multiplied by its weight (w) and the product summed to give a total value. Weights were summed to give a total weight. Total value was then divided by total weight to give the weighted mean for an objective in the hierarchy.

$$Weighted\ mean = (\sum x . w) / \sum w \tag{4.1}$$

Where x= transformed indicator values, w= weight of indicator

The transformed indicator time series provided the numerical inputs for the weighted mean used to aggregate indicators and objectives at each level through the objectives' hierarchy. This ultimately returns a value for the pressure and state objectives. The pressure and state objectives were then combined using weighted mean to return an overall value to evaluate the implementation of an EAF for the sardine-directed (the overall objective).

Choosing appropriate weights to represent the relative importance of indicators and objectives in the hierarchy is important to reflect the purpose of the tool as well as the current thinking around the ecological well-being dimension of EAF in the sardine fishery. The relevant importance of the objectives and indicators may vary and choosing to weight certain indicators higher than others may be as a result of perceived importance, methodological uncertainties (Goodwin and Wright, 2000) or for policy-driven reasons (Rice and Rochet, 2005). For example, there may be unequal uncertainty in the time series underlying the indicators, which may result in a lower weight selected for the time series that is less well defined. Additionally, stakeholders may want to select a higher weight for ecosystem indicators than sardine indicators to emphasise the ecosystem interactions of the sardine fishery by assuming that the current TROM-based management approach provides adequate protection of the sardine population.

4.3. Sensitivity analysis

4.3.1. Sensitivity analysis to changes in weight

The goal of the sensitivity analysis on weights was to test how different weighting scenarios affected the knowledge-based tool outputs for the pressure, state and overall objectives. Six scenarios were selected for weighting the objectives and indicators in the objectives' hierarchy. The first scenario represented an equal weighting across the hierarchy, whilst the other five scenarios gave a higher weight to the pressure objectives than the state objectives. State objectives, whether these are ecosystem related or sardine related, are affected by factors external to the fishery. For example, changes in the environment and predation or competition that cannot be influenced by fisheries management. For this reason they were assigned a lower weight in these scenarios as they would not reflect the same level/resolution of the progress made by management towards implementing an EAF.

To further test the sensitivity of changes in weight to the knowledge-based tool outputs, the variance between the five weight scenarios was calculated. Variance describes the distribution of values around the mean. If the variance is zero the weight scenarios will all have returned the same output, and it can be concluded that the output for an objective is robust to changes in weight. An increase in the variance will therefore indicate some difference between tool outputs under the different weight scenarios, suggesting that the outputs are more sensitive to changes in weight. The greater the variance the more sensitive the objective is to a change in weight.

4.3.2. Sensitivity analysis to changes in thresholds

To test the sensitivity of the objective outputs to the indicator threshold, each indicator threshold was increased by (i) 5% and (ii) 10% while the other indicators were kept at expert-determined threshold values. The indicator time series were then transformed against the new threshold parameters. A weighted mean summation was then applied for the stakeholder-selected weights. The same methodology was applied to the equal weights scenario to explore the effect weight selection would have on sensitivity to indicator thresholds.

4.4. Results

4.4.1. Selecting thresholds

Threshold values have been identified for each indicator and this section details the justification for the expert-selection of the thresholds. A summary of the threshold values are presented in Table 4.4.

Table 4.4: List of the expert-determined thresholds selected for each indicator. Threshold parameters were selected to represent a good (+1), okay or undetermined (0) and bad (-1) condition.

		Thresholds		
Indicators	**Unit**	**+1**	**0**	**-1**
Exploitation rate	Dimensionless	0.25	0.3	0.4
Bycatch of juvenile sardine	%	2	4	8
Proportion of sardine caught west of Cape Agulhas	%	10	20	40
Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Dimensionless	1	1.2	1.4
1^{+}SSB	Tonnes (t)	832 000	615 000	495 000
Relative weight	Dimensionless	102	101	100
Breeding pairs African penguins on western islands	Thousand pairs	45	30	15
Breeding pairs African penguins on eastern islands	Thousand pairs	25	15	10
Breeding pairs Cape cormorants	Thousand pairs	60	50	40
Breeding pairs Swift terns	Thousand pairs	10	5	1
Area occupied by breeding Cape gannets	Hectares (ha)	2	1.75	1.5

<u>Exploitation rate</u>

A limit reference point (a bad threshold) of 0.4 has been recommended by Patterson (1992) for exploitation rate of small pelagic fish in the southern Benguela ecosystem. Fairweather et al. (2006a) retained this threshold, recommending that if the exploitation rate exceeds 0.4, the fishery is not being successfully managed. Despite changes in the way exploitation rate is calculated in this chapter, the experts consulted agreed that the upper limit of exploitation rate should remain as previously presented, in line with Patterson (1992) and Fairweather et al. (2006a). From examining the time series and with the understanding of fishing pressure over the last few decades, the experts consulted agreed that years with an exploitation rate of less than 0.25 could be considered to be good, i.e. the fishery is not fishing the sardine stock too hard; a value of 0.3 was considered to be an okay exploitation rate, applying the precautionary principle; and a value of 0.4 was considered to be a bad exploitation rate.

Bycatch of juvenile sardine

Fishing cannot be entirely selective for adult sardine as some juveniles will be caught by the fishery each year. As such, some bycatch by the fishery should be accounted for when choosing thresholds. The experts consulted suggested that a bycatch of juvenile sardine in the sardine-directed fishery of 2% or less in any year was a sign of good fishing practice. A bycatch of 8% or higher was considered to be unsustainably high catch of juvenile sardine, and this threshold was identified from years where there was high recruitment and known levels of high bycatch (Fairweather et al., 2006a). A bycatch value of 4% was considered the okay threshold.

Proportion of sardine caught west of Cape Agulhas

In calculating this indicator, the biomass estimate presents a snapshot of the population distribution from a single annual survey and not accounting for year-round fishing impacts. Considering this, truly spatially proportionate fishing is difficult to achieve. The experts consulted considered an acceptable indication of spatially proportionate fishing to be the proportion of sardine caught WoCA being less than 10% of the available biomass situated WoCA. A good threshold was therefore defined as proportion of 10% for this indicator. This threshold also reflects the current management of the fishery which aims to maintain a TAC of approximately 10% of adult biomass (de Moor et al., 2011). A catch of 40% or greater of the sardine biomass situated WoCA was considered to be representative of spatially disproportionate fishing and is set as the bad threshold. Fishing far exceeded this threshold in the mid- to late-2000s when sardine biomass was found predominately to the EoCA (Coetzee et al., 2008b). The okay threshold was set at 20%.

Ratio of large sardine in the sardine-directed catch west of Cape Agulhas

The aim of this indicator is to maintain fishing of large sardine proportional to the amount of large sardine in the population, any ratio equal or less than one suggests that fishing of large sardine off the west coast is representative of spatially appropriate fishing. A ratio of anything greater than one indicates that some degree of spatially disproportionate fishing was occurring. As the fishery is not currently managed in a spatially explicit manner, stakeholders agreed that some degree of spatially disproportionate fishing may occur and to account for this the okay threshold, 1.2 was thought acceptable. A ratio of not more than 1.5 was considered to be unsustainable as it could put parts of the population at risk to overfishing and/or lead to genetic diversity depletion.

1^+Spawner stock biomass

The OMP-08 uses the probability of the sardine population size falling below the average 1991-1994 biomass estimates as a risk definition against which to test the model (de Moor and Butterworth, 2008). OMP-08 is tuned to ensure that the probability of the biomass estimates falling below this level at least once over the projection period of 20 years is minimised. In determining thresholds for the indicator 1^+SSB, the risk threshold of 495 000t is considered to be the lowest acceptable sardine population biomass below which the recovery of the sardine population may be compromised, and experts agreed that this level should provide the bad threshold for this indicator. The upper threshold, representing the point where sardine biomass is thought to be good, was calculated from the posterior probability density function for the lower threshold and was determined to be 832 000t. The median threshold of 615 000t was determined from the posterior probability density function in the OMP testing process. This represents the okay threshold.

Sardine relative weight

Thresholds for sardine relative weight were based on Ndjaula et al. *(*2013) using quartiles (Upper Q3, Lower Q1 and Median Q2) of relative weight to estimate thresholds based on mean relative weight of 101%. The lower quartile returns a relative weight of 100%, and the upper quartile returns a relative weight of 102%. From these thresholds a year with a low relative weight can be determined. A relative weight of less than 100% is indicative of very poor condition of the sardine population and is used to define the 'bad' threshold. A year returning a relative weight above the upper quartile of 102% indicates a period of good condition of sardine in the population. A median relative weight of 101% is considered the okay threshold for the sardine population.

Breeding pairs of African penguins on western islands

African penguins have experienced a major decline in population numbers since the beginning of the century. In the Western Cape, African penguin breeding pairs have further declined from an average of 35 000 pairs in the period 2001-2005 to just 11 000 pairs in 2009 (Crawford et al., 2011). When determining threshold values for the indicators of African penguin health, penguin experts agreed that if the population fell below 15 000 breeding pairs in the Western Cape there would be little chance of recovery, and this was therefore set as the lower threshold value. Ideally, a penguin population in good condition should be 45 000 breeding pairs or more, and so this is used as the good threshold. An okay threshold of 30 000 breeding pairs was set by the experts consulted. The precautionary principle was explicitly applied by the experts to the African penguin thresholds as this species is classified as Endangered on the IUCN Red Data List.

Breeding pairs of African penguins on eastern islands

The seabird experts consulted agreed that if the number of breeding pairs of African penguins in the Eastern Cape fell below 10 000 the population may not recover, thus 10 000 breeding pairs was selected as the bad threshold. The numbers of penguins on eastern islands in the last decade have come close to this threshold; and this period is well documented as a major decrease in the number of breeding pairs on these islands (Crawford et al., 2011). Ideally, 25 000 breeding pairs or more in the Eastern Cape would indicate that the penguin population is in good condition and is therefore considered the good threshold, while 15 000 breeding pairs is considered the okay threshold.

Breeding pairs of Cape cormorants

During the early 1990s the number of breeding pairs of Cape cormorants varied between 70 000 and 80 000 pairs (Crawford et al., 2007a). Since then population numbers declined and Cape cormorants have held a low but stable population over the past decade, fluctuating around 30 000 breeding pairs. The 1990s was a period of recovery for the sardine stocks, indicating good prey availability for the seabirds. Experts would like to see cormorant populations back to those numbers, and thus the good threshold value of 60 000 breeding pairs was agreed upon. Population numbers below 40 000 pairs were considered the bad threshold, according to stakeholders. Experts agreed that 50 000 breeding pairs could be considered to represent the okay threshold.

Breeding pairs Swift terns

The number of breeding pairs of Swift terns has shown a steady increase since 1997 and is related to sardine and anchovy availability, despite not decreasing during recent sardine biomass decline. Experts agreed that 10 000 pairs of swift terns is a good indicator of the health of this population. Any population decline to below 1 000 pairs may signal a bad situation for Swift terns, and hampers their ability to increase in the presence of fishing. During years of high sardine biomass, and before the recent increase in the swift tern population, the population remained stable at around 5 000 breeding pairs, as a result this was suggested by the experts as a reliable okay threshold value.

Area occupied by breeding Cape gannets

The status of Cape gannet populations is of concern to biologists and these species have been listed as Vulnerable on the IUCN red data list. The area occupied by breeding pairs of Cape gannets remained relatively stable around 2 ha over the period 1994-2001; and whilst this area reduced dramatically in 2004, it has showed signs of recovery since then. Experts agreed that the threshold indicating a good situation for Cape gannet populations should therefore be 2 ha, as this was a period of high population numbers in the Western Cape. An area occupied by breeding pairs of Cape gannets 1.5 ha or less is considered the bad threshold, with 1.75 ha as the okay threshold.

4.4.2. Transforming indicators

The indicator threshold parameters were used to transform the indicators to a common scale using a numerical transformation from +1 to -1. The expert-determined threshold parameters and indicator trends displayed once the indicators were transformed were considered representative of the indicator over time by the stakeholders consulted in the two stakeholder meetings held.

4.4.3. Selecting weights

Table 4.5 presents the weights selected by for the indicators and objectives in the objectives' hierarchy individual stakeholders during a meeting with the EAF-SWG. Recognising that the stakeholder's decisions may be influenced by their areas of interest, the stakeholders' research field is presented at the top of Table 4.5 (see Table 4.3 for the list of stakeholders consulted when selecting weights). From these weight selections a final set of weights for the objective hierarchy was agreed upon and is presented in Table 4.6. Consensus on weight selection was reached by the stakeholders for most of the objectives. All stakeholders rated the broad objective measuring pressures exerted by the sardine fishery on the ecosystem was rated higher than the state-related broad objective. Pressures can be controlled through management interventions, and therefore provide some indication of the progress made to implement an EAF in the sardine fishery. While the state of the ecosystem is important to monitor, it was assigned a lower weight in the objectives' hierarchy because environmental drivers such as climate variability will influence these indicators, but cannot be directly influenced by fisheries management.

Table 4.5: Stakeholder selected weights for the indicators and objectives in the knowledge-based tool.

Stakeholder consulted		**1**	**2**	**3**	**4**	**5**	**6**	**7**
Stakeholder's area of expertise		Top predators	Top predators	Seabirds	Seabirds	Sardine	Sardine and EAF	EAF
Management objective	**Indicator**	**Weights selected by stakeholders (%)**						
Pressures exerted by the sardine fishery		**70**	**60**	**70**	**60**	**70**	**70**	**70**
Optimise sardine mortality		20	50	25	40	40	40	20
	Sardine exploitation rate	80	60	60	50	50	60	60
	Bycatch of juvenile sardine	20	40	40	50	50	40	40
Eliminate spatially disproportionate fishing		80	50	75	60	60	60	80
	Proportion of sardine caught west of Cape Agulhas	50	35	75	40	70	40	30
	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	50	65	25	60	30	60	70
State of the southern Benguela		**30**	**40**	**30**	**40**	**30**	**30**	**30**
Maintain target species in highly productive state		20	30	30	30	20	40	30
	1^{+}SSB	70	70	70	60	60	70	70
	Sardine relative weight	30	30	30	40	40	30	30
Maintain forage base for seabird		80	70	70	70	80	60	70
	Breeding pairs of African penguins on western islands	35	35	35	40	40	35	35
	Breeding pairs of African penguins on eastern islands	20	20	20	20	15	20	20
	Breeding pairs of Cape cormorants	15	15	15	10	10	15	15
	Breeding pairs of Swift terns	15	15	15	15	10	15	15
	Breeding pairs of Cape gannets	15	15	15	15	25	15	15

Table 4.6: Final suite of weights used in aggregating the indicators and objectives in the knowledge-based tool.

Management objective	Weight (%)	Indicator	Weight (%)
Pressures exerted by the sardine fishery are managed carefully	**70**		
Optimise sardine mortality	*20*		
		Sardine exploitation rate	60
		Bycatch of juvenile sardine	40
Eliminate spatially disproportionate fishing	*80*		
		Proportion of sardine caught west of Cape Agulhas	70
		Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	30
State of the southern Benguela is not negatively affected by fishing	**30**		
Maintain target species in highly productive state	*30*		
		1^{+}SSB	70
		Sardine relative weight	30
Maintain forage base for seabird	*70*		
		Breeding pairs of African penguins on western islands	40
		Breeding pairs of African penguins on eastern islands	20
		Breeding pairs of Cape cormorants	10
		Breeding pairs of Swift terns	10
		Breeding pairs of Cape gannets	20

The objectives' hierarchy is divided into objectives for pressure and state. Within both these broad objectives, the specific objectives can be divided into those that relate to the ecosystem and those that related to the target species (sardine). The sardine-related objectives link to indicators that measure impacts on the target stock, while ecosystem-related objectives link to indicators which show the impact fishing has on broader ecosystem issues, for example the health of seabird populations and the impact of spatially disproportionate fishing (Table 4.6). The sardine-related objectives for both pressure and state were weighted lower than the ecosystem-related objectives. The reason provided for these weight selections is that current fisheries management is already focused on managing the impacts of fishing on the target stock and will continue to carry out this role, while an EAF requires fisheries management to broaden its scope to include the impacts of the fishery on the ecosystem. It was assumed that as an EAF is implemented in the sardine fishery, a response in the ecosystem-related objectives will be observed, thus the higher weight emphasises the EAF perspective to complement the TROM-based management approach.

The goal of the current sardine OMP is to ensure that sardines are optimally exploited. The indicator of sardine exploitation rate was rated slightly higher than the indicator of juvenile sardine bycatch. The bycatch of juvenile sardine is thought to be underreported in the fishery as there are reports of discarding juvenile sardine at sea by the fishery (Hara et al., 2013), so stakeholders assumed higher uncertainty in this indicator.

Stakeholders considered the objective to '*Eliminate spatially disproportionate fishing'* very important and is reflected in the selected weight (see Table 4.6). The shift of sardine biomass from the west to south coast of South Africa has had significant impacts on the availability of sardine to top predators. This has raised concerns among stakeholders that fishing, which is not currently managed spatially, may deplete the remaining stock situated WoCA disproportionately to the sardine situated EoCA (Coetzee et al., 2008b). As a result of these concerns, this objective is weighted much higher than the indicator '*Optimise sardine mortality*'. However, not all stakeholders weighted this indicator higher. Some stakeholders recommended that the indicator '*Ratio of large sardine in the sardine-directed catch west of Cape Agulhas*' should be weighted higher, stating that large sardine are important for prey availability for seabirds and other predators and that large sardine are required to contribute to the re-building of the spawning stock off the west coast.

After some discussion with experts it was agreed that, while the indicator for the spatialised catch of large sardine east and west of Cape Agulhas is a more plausible indicator for addressing the concerns around spatially disproportionate fishing of sardine stocks in South Africa, the development of this indicator has been difficult. This indicator displays a variable trend across the period and the cut-off length to define large sardine is biologically variable (Coetzee, 2006, Coetzee and Merkle, 2007). As a result, the indicator signal is not clear enough in view of the objective and it was decided to give a higher weight to the indicator of the '*Proportion of sardine caught west of Cape Agulhas*' than the number of large sardine caught. The indicator of spatialised sardine catches is a weaker than the large sardine catch indicator in terms of the objective, but there is greater confidence in the data underpinning this information. The signal is clearer and does not rely on cut-off levels; as a result, the stakeholders agreed that this indicator should receive a higher weight in the objectives' hierarchy.

The state objectives are similarly divided into sardine-related and ecosystem-related indicators. The objective of maintaining the target species in a highly productive state was given less weight than maintaining a forage base for dependent seabirds. The reason for this decision is that the target stock is already conservatively managed by the OMP. Model-predicted 1^{+}SSB is used as an indicator in the OMP, and the sardine population assessment relies heavily on this output for management decisions. The indicator pertaining to relative weight of sardine is weighted lower than 1^{+}SSB, because sardine condition is thought to be of less importance for a healthy sardine population than the overall stock size.

Seabirds are strongly influenced by the availability of small pelagic fish for food (Crawford et al. 2006, 2007a, 2008, 2009, 2011, Oakes et al., 2009). African penguins are classified as Endangered on the IUCN Red Data List and as such the effect of the small pelagic fishery on this species is of most concern to stakeholders. African penguin colonies on islands in the Western Cape are most vulnerable to localised decreases in prey (Crawford et al., 2011, Sherley et al., 2013), as they have a restricted foraging range when breeding (approximately 20-40km) and the west coast of South Africa is where most of the sardine-directed fishing is situated. As such, African penguin condition on western islands was given the highest weight in this objective. The indicator of African penguin breeding numbers on islands in the Eastern Cape was weighted lower than the Western Cape population indicator. African penguin populations on the Eastern Cape islands have not been consistently monitored over time; consequently, the time series underpinning this indicator is less certain than for the indicator of African penguin condition on western islands.

Cape gannets are classified as Vulnerable on the IUCN Red Data List and therefore more susceptible to population decreases related to prey availability than Swift terns (Least Concern) and Cape cormorants (Threatened), whose populations have been stable or increasing despite declines in sardine biomass. All three of these species have larger foraging ranges than African penguins, thus less likely to be affected by localised overfishing, and as a result are given a lower weight than the African penguin indicators.

4.4.4. Outputs of the knowledge-based tool

Figure 4.2 shows the change over time in the outputs for the Pressure and State objectives. Indicators and specific objectives are combined through the objectives' hierarchy using a weighted mean to provide outputs indicating the progress towards meeting the objective. The final weights selected by stakeholders were used to calculate the output values. The values returned for the pressure objective indicated negative values from 1988-1990, that improved to mostly the positive values in 1991-1995. A negative trend was then detected in 1996 and 1997, followed by two years of high positive values. The overall trend for the 2000s returned negative output values, with improvement in 2009 returning a positive output. The outputs returned for the state objective showed a more gradual trend over time, dividing into three periods. From 1987-1995 negative values were returned, from 1996-2000 they were positive and from 2001-2009 the outputs returned negative values.

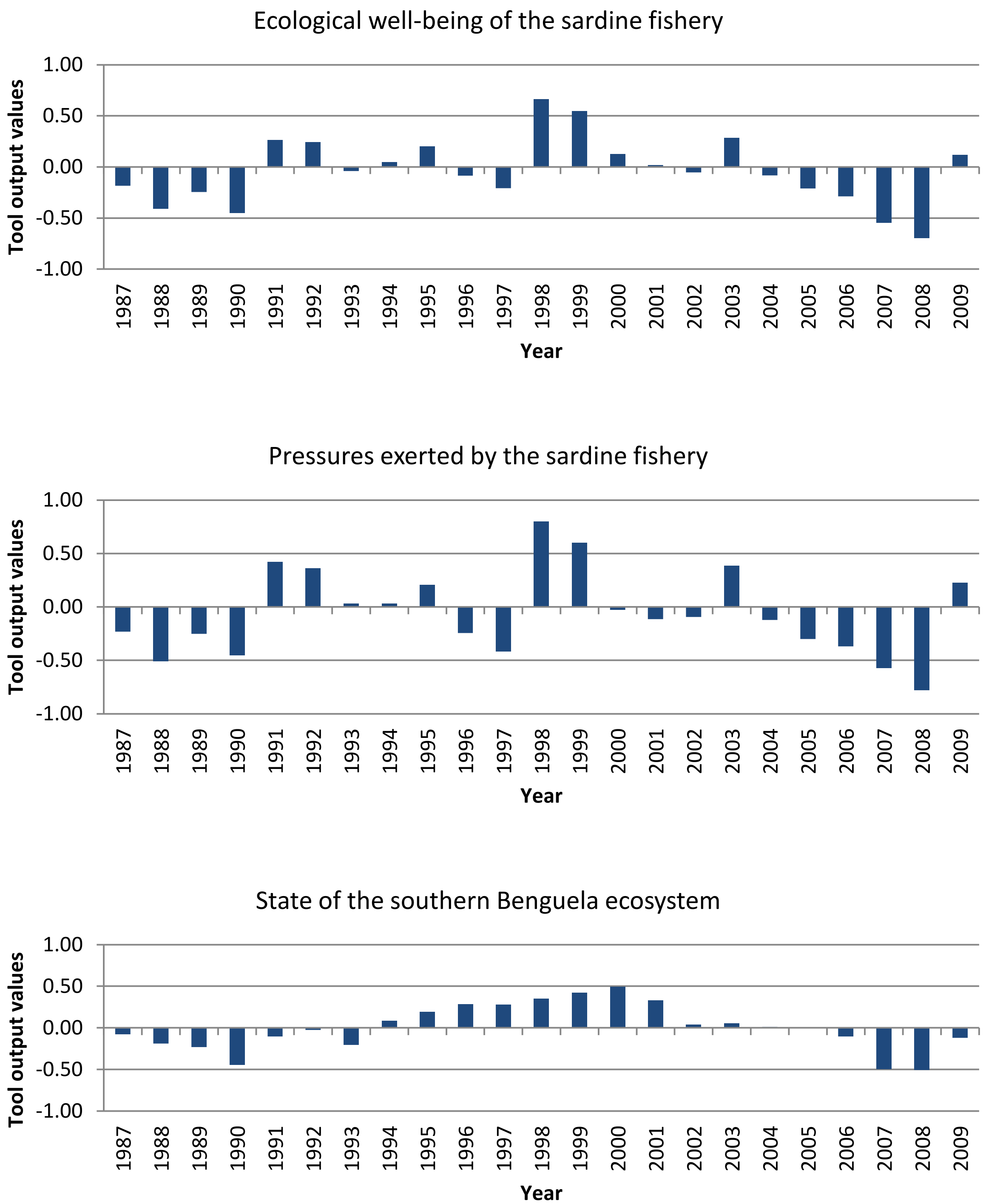


Figure 4.2: The knowledge-based tool outputs for the time period 1987-2009. The time line is presented separately for the objectives (i) The overall Ecological well-being of the sardine fishery, (ii) Pressures exerted by the sardine fishery, and (iii) the State of the southern Benguela ecosystem.

4.4.5. Sensitivity analysis

4.4.5.1. Sensitivity analysis on weight scenarios

Six weight scenarios were identified to test the sensitivity of the pressure, state and overall EAF implementation objectives to changes in the selected weights (Table 4.7). The following figures show the knowledge-based tool outputs for the three objectives. It was assumed that the greater the change in the output for an objective in a given year, the more sensitive that objective is to changes in weight.

The numerical outputs of the knowledge-based tool for the pressure objective under the six weight scenarios are shown in Figure 4.5. For a summary of the weight scenarios see Table 4.6. Scenario 2, high weights on sardine-related indicators, was the most variable. This scenario consistently returned the highest values in years when the output was positive and the lowest values in years when the output was negative. The scenarios which weighted sardine-related indicators higher (scenarios 2 and 4) tended to group together and separately from the ecosystem weight scenarios (scenarios 3 and 5) with the ecosystem-related scenarios returning lower values. In general, however, the scenarios followed a similar pattern across the time series, but in the mid-2000s this pattern changed with sardine-related scenarios decreasing from 2003-2004 and ecosystem weight scenarios increasing over the same period. Scenario 6, where the final weights were selected for the knowledge-based tool by stakeholders, followed the pattern of the two ecosystem–related scenarios, but deviated somewhat in the mid-2000s returning lower outputs from 2004. This is a result of the high weighting of the ecosystem indicators in this objective compared to the weights in scenarios 3 and 5.

Table 4.7: Description of the six weight scenarios applied in testing the sensitivity of the knowledge-based tool to changes in weight selection.

No.	Weight scenario	Description	Motivation for weight scenario selection
1	Equal weights	Indicators and objectives are weighted equally in the objectives' hierarchy	Provides a baseline for comparing results of the sensitively analysis.
2	Hard sardine weights	High weights selected for sardine related objectives in the objectives' hierarchy	The pressures exerted on the ecosystem are affected by management actions, while state indicators are influenced both by fishing and environmental changes. The uncertainty for ecosystem indicators is slightly higher than sardine indicators. To address uncertainties, the sardine indicators which are currently included in fishery management are given a higher weight in this scenario.
3	Hard ecosystem weights	High weights selected for ecosystem related objectives in the objectives' hierarchy	This scenario aims to build EAF approach to compliment the traditional management processes by weighting ecosystem indicators higher than sardine indicators.
4	Moderate sardine weights	Moderate weight for sardine related objectives in the objectives' hierarchy	Offers less extreme weighting than the hard weight scenarios. Choosing to weight sardine-related indicators higher than ecosystem indicators. Reflects current management approaches in the sardine fishery.
5	Moderate ecosystem weights	Moderate weight on ecosystem related objectives in the objectives 'hierarchy	This is reflective of weights provided by participants in the Pringle Bay meeting in 2007. These provide a baseline of EAF-based thinking around objective weighting, weighting ecosystem indicators higher than sardine-related indicators. Less extreme weighting than the hard weight scenarios.
6	Final stakeholder weights	Moderately pressure focused, emphasis on ecosystem impacts in the objectives' hierarchy	Weights selected by stakeholders and used to aggregate indicators and objectives in the knowledge-based tool. This scenario is considered the most representative of current thinking around EAF in the sardine-directed fishery.

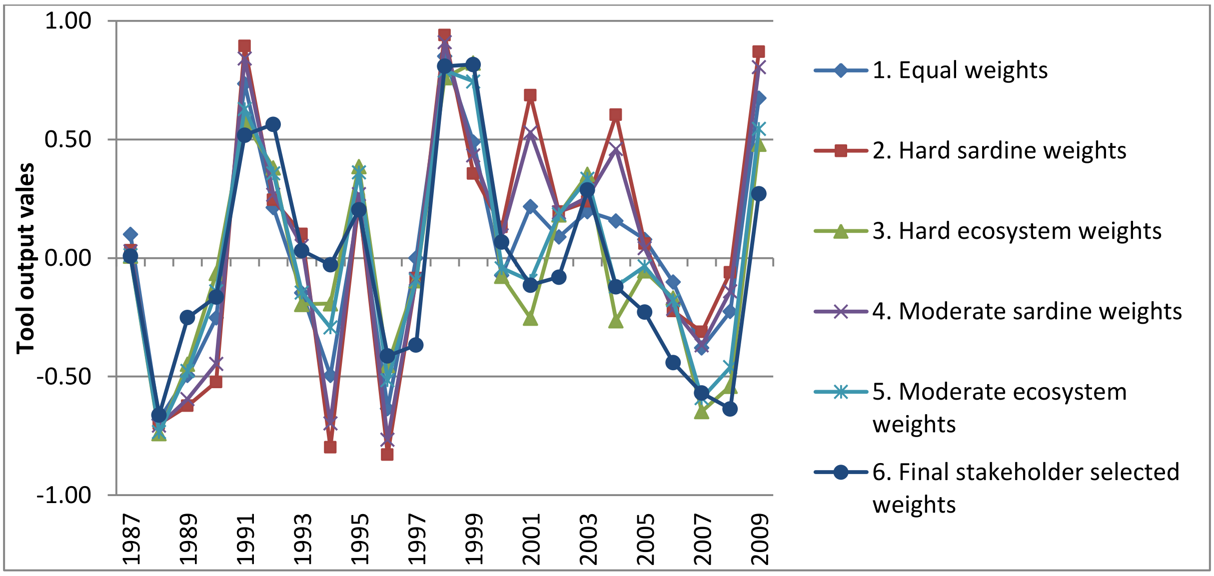


Figure 4.3: Change in the output value of the pressure objective for a weighted mean summation for the six weight scenarios.

Figure 4.4 presents the numerical outputs of the knowledge-based tool over time for the state objective under the six weight scenarios. Similar to the pressure objective, the scenarios 2 and 4 weight scenarios group separately to scenarios 3 and 5, with the high sardine weighted scenario (scenario 2) consistently returning the highest and lowest (in all but one case) values across the time series. In 2003 the sardine-related weight scenarios continued to show positive values, while scenarios 1, 3, 5 and 6 all displayed negative values from 2002. In 2007 the output patterns came together returning negative values for all weight scenarios for the rest of the time period.

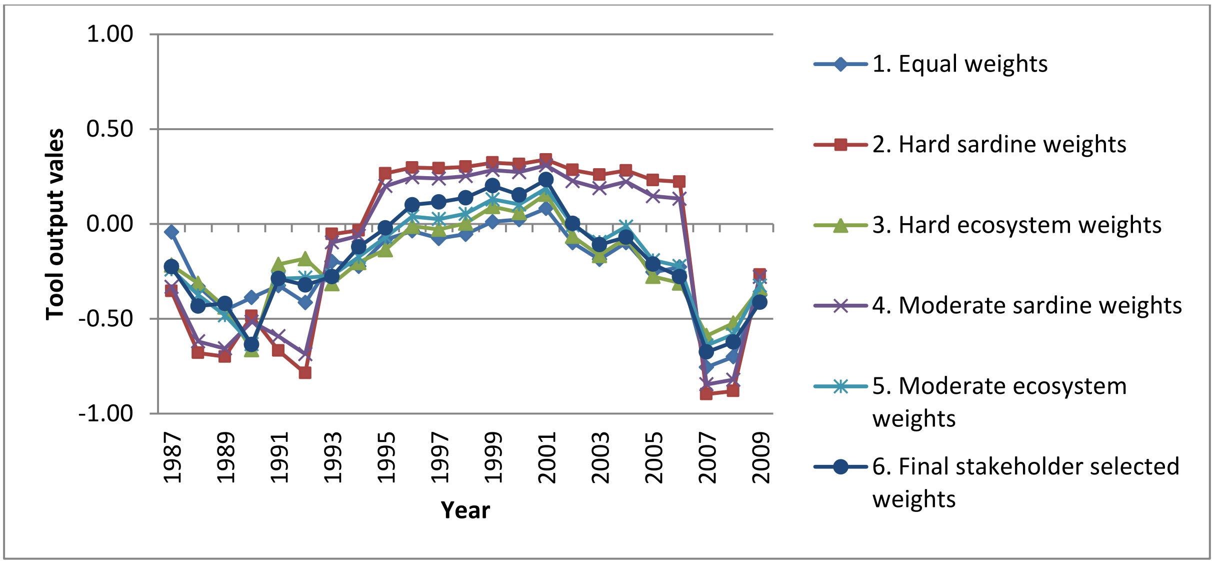


Figure 4.4: Change in the output value of the state objective for a weighted mean summation for the six weight scenarios.

The overall objective combined the pressure and state objectives in a weighted mean to produce an output for the overall EAF implementation efficacy each year (Figure 4.5). Scenarios 2 and 4 separate out from scenarios 3 and 5, with the high sardine weighted scenario (Scenario 2) returning the most variable results and the moderate ecosystem weighed scenario (scenario 5) presenting the lowest variability over the time period. The outputs returned, however, were consistently lower than those for the pressure objective (Figure 4.3); which suggested that a precautionary approach was taken by stakeholders in the scientific working groups to weight selection, possibly reflecting the management of the sardine fishery.

For all objectives, the outputs returned under the tested weight scenarios show that the scenarios weighting sardine indicators higher produced consistently more variable outputs - that is, more positive and more negative than the other scenarios. The ecosystem-related scenarios consistently returned less variable output values. The weights selected by the stakeholders (scenario 6) more closely reflected the weights used in the ecosystem-related scenarios than the sardine-related ones, which is not surprising as the experts were more focused on emphasising ecosystem impacts which align closer to the goals of EAF implementation in the sardine fishery

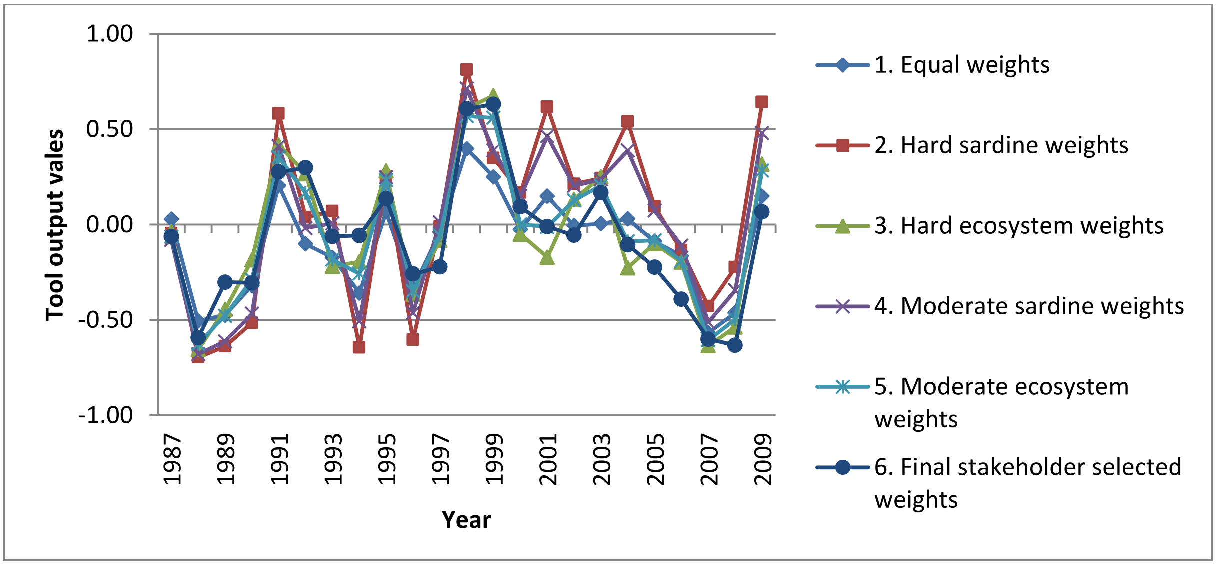


Figure 4.5: Change in the output value of the overall objective for a weighted mean summation for the six weight scenarios.

Figure 4.6 presents the variance between the weight scenarios over the time for the pressure, state and overall objectives. The variance was low across all three time series, ranging from a minimum of zero to maximum 0.15. The mean variance for the pressure objective was 0.03, suggesting that the outputs varied 3% on average between the six weight scenarios. The pressure objective returned a variance close to zero in most years, but displayed three years of high variance of 10% in 1994, 15% in 2001 and 12% in 2004. Similarly, the overall objective displayed two years of high variance in 2001 and 2004. The average variance across the time series for the state and overall objectives were slightly lower at 0.02 (2%), but only one year (2009) in the time series returned a variance of zero. The low variance suggests that the choice of weights have little effect on the outputs returned in the knowledge-based tool for the three objectives in most years, but that the pressure objective may be more sensitive to changes in weight than the state objective.

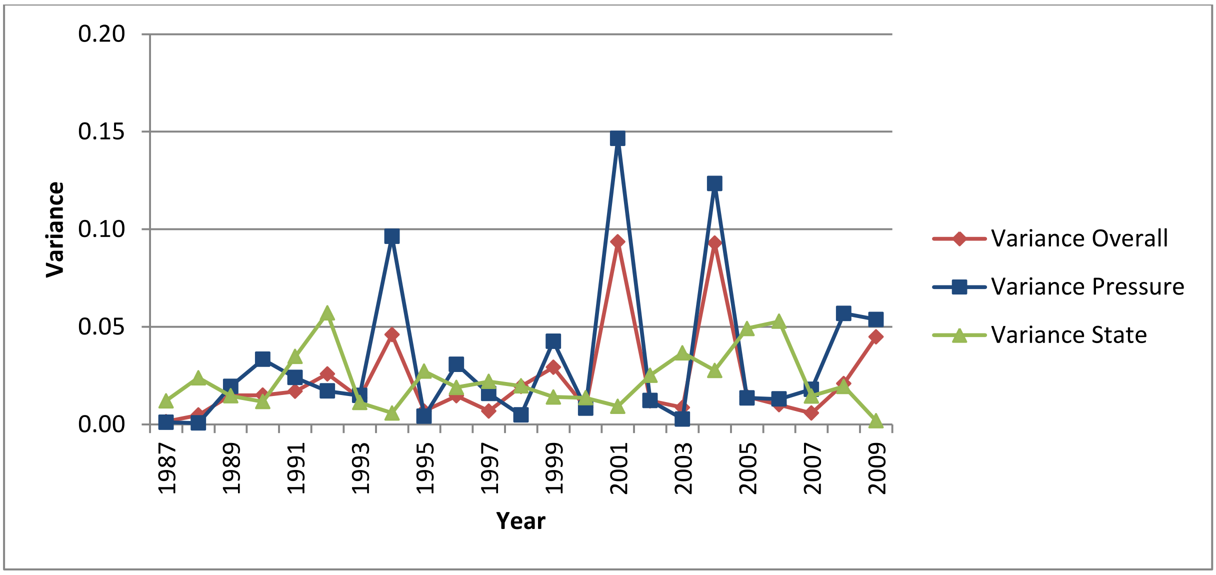


Figure 4.6: The variance around the mean for the six weight scenarios for the pressure, state and overall objectives.

4.4.5.2. Sensitivity analysis on changes in threshold values

To test the sensitivity of the objective outputs to the indicator threshold, each indicator threshold was first increased by 5% and then by 10% while the other indicators were kept at expert-determined threshold values. A weighted mean calculation was run, using the newly transformed indicator values, and provided an indication of which indicator was most sensitive to a change in threshold values under the stakeholder-selected weight scenario (scenario 6, see Table 4.6). Table 4.8 provides a summary of the indicators that contributed to the greatest change in objective output from the original set of thresholds for each year of the time series.

The pressure objective displays a consistent trend throughout the time series when increasing the threshold parameters by 5% and 10%, with agreement on which indicator contributed to the greatest change from the original across the weight scenarios and over the majority of years (Table 4.8). For all years in the time series, except 1987 when spatially disproportionate fishing was not calculated, the indicators of spatially disproportionate fishing, the '*Proportion of sardine caught west of Cape Agulhas*' and the '*Ratio of large sardine in the sardine-directed catch west of Cape Agulhas*' contributed to the greatest change from the original value. This indicated that the pressure objective is most sensitive to changes in the thresholds of the indicators of spatially disproportionate fishing.

The change in the output values for the state objective was not as clear cut as the pressure objective. In the early part of the time series, 1987-1990, the indicator '*Sardine relative weight*' contributed most significantly to a change in value from the original output. From 1997-2009, indicators of seabird health contributed to the change from the original output value (Table 4.8). This suggested that for the early part of the time series the state objectives are more sensitive to changes in thresholds of '*Sardine relative weight*', while in later time series the indicator '*Breeding pairs of Cape gannets'* contributed more to the sensitivity of the state objective.

Table 4.8: Summary of the indicator(s) contributing to the greatest changeto the output values for the pressure, state and overall objectives when a 5% and 10% change is made to threshold parameters under the expert-selected weight scenario.

Year	**Pressure objective**		**State objective**		**Overall objective**	
Change in threshold	5%	10%	5%	10%	5%	10%
1987	Exploitation rate	Exploitation rate	Relative weight	Relative weight	Relative weight	Relative weight
1988	Proportion of sardine caught west of Cape Agulhas	Proportion of sardine caught west of Cape Agulhas	Relative weight	Area occupied by Cape gannets	Proportion of sardine caught west of Cape Agulhas	Proportion of sardine caught west of Cape Agulhas
1989	Proportion of sardine caught west of Cape Agulhas	Proportion of sardine caught west of Cape Agulhas	Relative weight	Relative weight	Proportion of sardine caught west of Cape Agulhas	Proportion of sardine caught west of Cape Agulhas
1990	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Relative weight	Relative weight	Relative weight 1^+SSB	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas
1991	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Proportion of sardine caught west of Cape Agulhas	1^+SSB	Area occupied by Cape gannets	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas
1992	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Area occupied by Cape gannets	Area occupied by Cape gannets	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas Proportion of sardine caught west of Cape Agulhas
1993	Proportion of sardine caught west of Cape Agulhas	Proportion of sardine caught west of Cape Agulhas	1^+SSB	1^+SSB	1^+SSB	Proportion of sardine caught west of Cape Agulhas
1994	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	1^+SSB	Area occupied by Cape gannets	1^+SSB	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas

Table 4.8 continued

Year	Pressure objective		State objective		Overall objective	
Change in threshold	5%	10%	5%	10%	5%	10%
1995	Proportion of sardine caught west of Cape Agulhas	Proportion of sardine caught west of Cape Agulhas	1^{+}SSB	Area occupied by Cape gannets	Proportion of sardine caught west of Cape Agulhas	Proportion of sardine caught west of Cape Agulhas
1996	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	1^{+}SSB	Area occupied by Cape gannets	1^{+}SSB	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas
1997	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Proportion of sardine caught west of Cape Agulhas	Area occupied by Cape gannets	Area occupied by Cape gannets	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Proportion of sardine caught west of Cape Agulhas
1998	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Area occupied by Cape gannets	Area occupied by Cape gannets	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas
1999	Proportion of sardine caught west of Cape Agulhas	Proportion of sardine caught west of Cape Agulhas	Area occupied by Cape gannets	Area occupied by Cape gannets	Proportion of sardine caught west of Cape Agulhas Area occupied by Cape gannets	Area occupied by Cape gannets
2000	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Area occupied by Cape gannets	Area occupied by Cape gannets	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas
2001	Proportion of sardine caught west of Cape Agulhas	Proportion of sardine caught west of Cape Agulhas	Area occupied by Cape gannets	Area occupied by Cape gannets	Proportion of sardine caught west of Cape Agulhas	Proportion of sardine caught west of Cape Agulhas
2002	Proportion of sardine caught west of Cape Agulhas	Proportion of sardine caught west of Cape Agulhas	Area occupied by Cape gannets	Area occupied by Cape gannets	Proportion of sardine caught west of Cape Agulhas	Proportion of sardine caught west of Cape Agulhas

Table 4.8 continued

Year	Pressure objective		State objective		Overall objective	
Change in threshold	5%	10%	5%	10%	5%	10%
2003	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Breeding pairs of Penguins western islands	Breeding pairs of Penguins western islands	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas
2004	Proportion of sardine caught west of Cape Agulhas	Proportion of sardine caught west of Cape Agulhas	Breeding pairs of Penguins western islands Breeding pairs of Penguins eastern islands Breeding pairs of Cape cormorants	Breeding pairs of Penguins western islands	Proportion of sardine caught west of Cape Agulhas	Proportion of sardine caught west of Cape Agulhas
2005	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Breeding pairs of Penguins western islands	Breeding pairs of Penguins western islands	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas
2006	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	1^+SSB	Breeding pairs of Penguins western islands Breeding pairs of Penguins eastern islands	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas 1^+SSB	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas
2007	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Breeding pairs of Penguins western islands	Breeding pairs of Penguins western islands	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas
2008	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Breeding pairs of Penguins western islands	Breeding pairs of Penguins western islands	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas	Ratio of large sardine in the sardine-directed catch west of Cape Agulhas
2009	Proportion of sardine caught west of Cape Agulhas	Proportion of sardine caught west of Cape Agulhas	1^+SSB	1^+SSB	1^+SSB	1^+SSB

A more detailed look at the same information was taken by plotting the absolute difference between the original objective outputs (derived from threshold parameters agreed upon by experts) and the new objective outputs (resulting from changing a single indicator as transformed from increasing expert determined threshold parameters by 5% or 10%). The new outputs showed a change in a single indicator at a time, while all other indicators were kept at the expert derived threshold transformations. Figures 4.7, 4.8 and 4.9 are presented as bar graphs for ease of comparison over time and within each year.

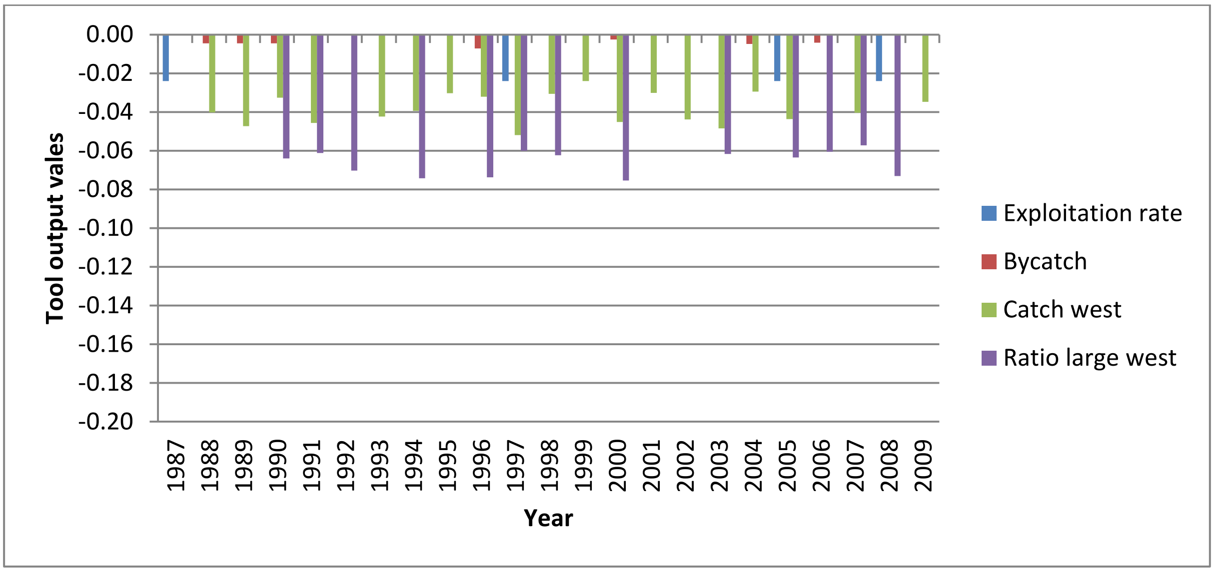
For the pressure objective, the indicator the '*Ratio of large sardine in the sardine-directed catch west of Cape Agulhas*' contributed most significantly to the differences observed (Figure 4.7). The indicator the '*Proportion of sardine caught west of Cape Agulhas*' contributed to a lesser degree. Under the 5% change scenario, indicators of sardine mortality did not contribute to changes observed, while exploitation rate contributed to make very small changes in the 10% change scenario. The 10% change scenario resulted in a higher magnitude of change from the original as would be expected, with output changes ranging from 0 to 0.14, while the 5% change returned a maximum difference of 0.08.

Figure 4.8 shows the results of this sensitivity test for the state objectives. The indicator '*Sardine relative weight*' contributed the most to changes in output values, but only until 1991, with the indicator '*Breeding pairs of Cape gannets*' contributing most significantly thereafter. The average magnitude of change was lower for the 5% thresholds than it was for the 10% thresholds. However, the indicator '*1^+SSB*' contributed to very high differences in a number of years over the time period.

The absolute difference in overall objective output values from the original resulted in the indicator '*Ratio of large sardine in the sardine-directed catch WoCA*' contributing most significantly to changes observed, although most years showed some change in the indicators, the *'Ratio of large sardine in the sardine-directed catch west of Cape Agulhas*, '*1^+SSB*' and '*Sardine relative weight*' contributions in 1994 and 1996

(Figure 4.9). Seabird and sardine mortality indicators did not feature significantly; however, more contribution to '*Breeding pairs of Cape gannet*' could be seen in the 10% threshold scenario. The overall objective showed a much lower magnitude of change over time than that of the pressure or state objectives separately.

The results of the final stakeholder agreed weights (scenario 6; see Table 4.6) were compared to an equal weight scenario (scenario 1) to test if the weights selected would have an effect on the sensitivity of the objectives and indicators to changes in threshold parameters. Comparing the results of these alternative weights to changes in indicator thresholds found agreement for both the state and pressure objectives on which indicators contributed most significantly to a change from the original threshold values, regardless of whether weighted mean or equal weights were applied. The magnitude of change differed between alternative weights, with the equal weight scenario displaying a much higher absolute difference than the stakeholder agreed weights (a difference up to 0.06), but not in terms of ranking. Other than this, however, there was very little difference in the trends observed between the 5% and 10% threshold scenarios under the different weights, i.e. the same indicators contributed to the sensitivity in changes to threshold parameters in the knowledge-based tool.



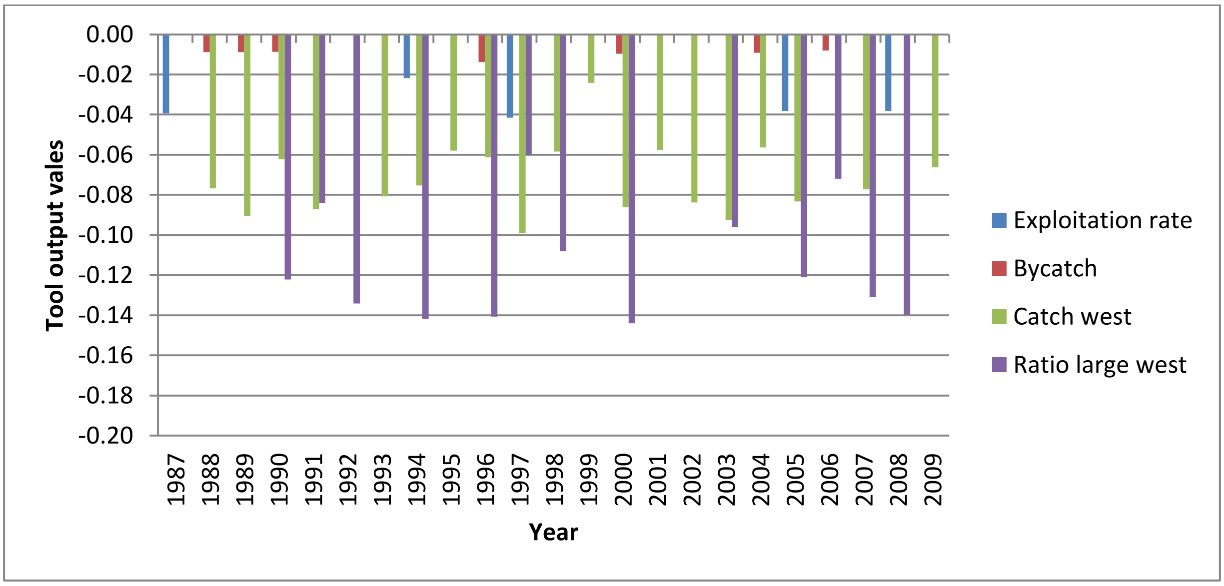
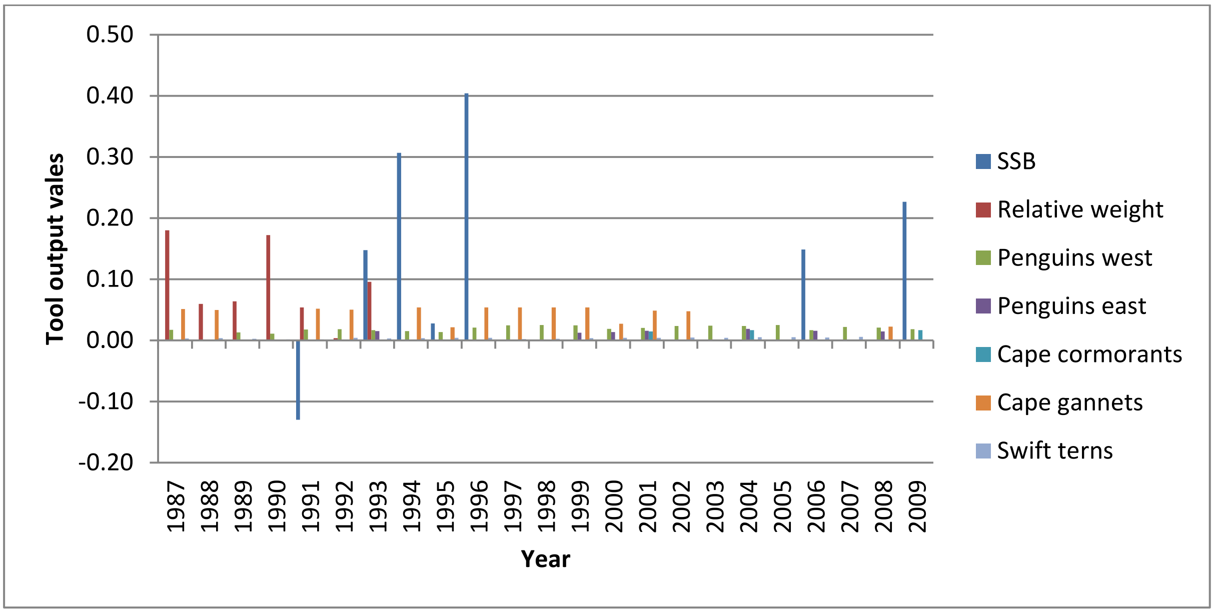


Figure 4.7: Absolute change in tool output value for the pressure objective when one indicator is changed by (i) adding 5% to thresholds used to transform the indicator and (ii) adding 10% to thresholds used to transform the indicator while keeping other indicators at the baseline (expert-determined) values.



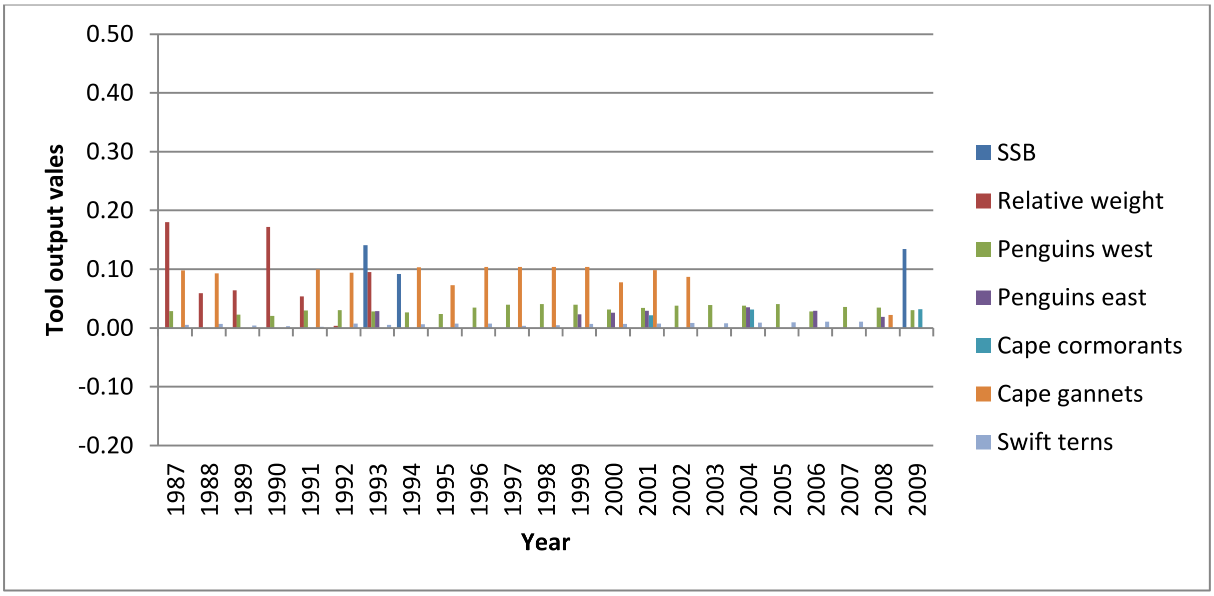
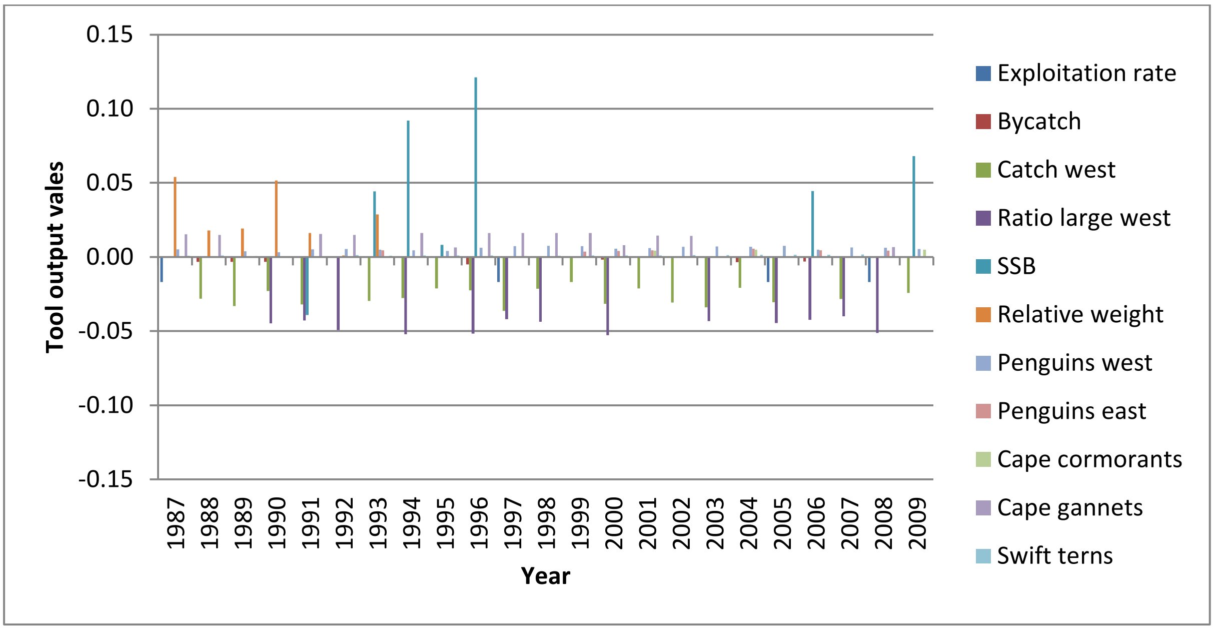


Figure 4.8: Absolute change in tool output value for the state objective when one indicator is changed by (i) adding 5% to thresholds used to transform the indicator and (ii) adding 10% to thresholds used to transform the indicator while keeping other indicators at the baseline (expert-determined) values.



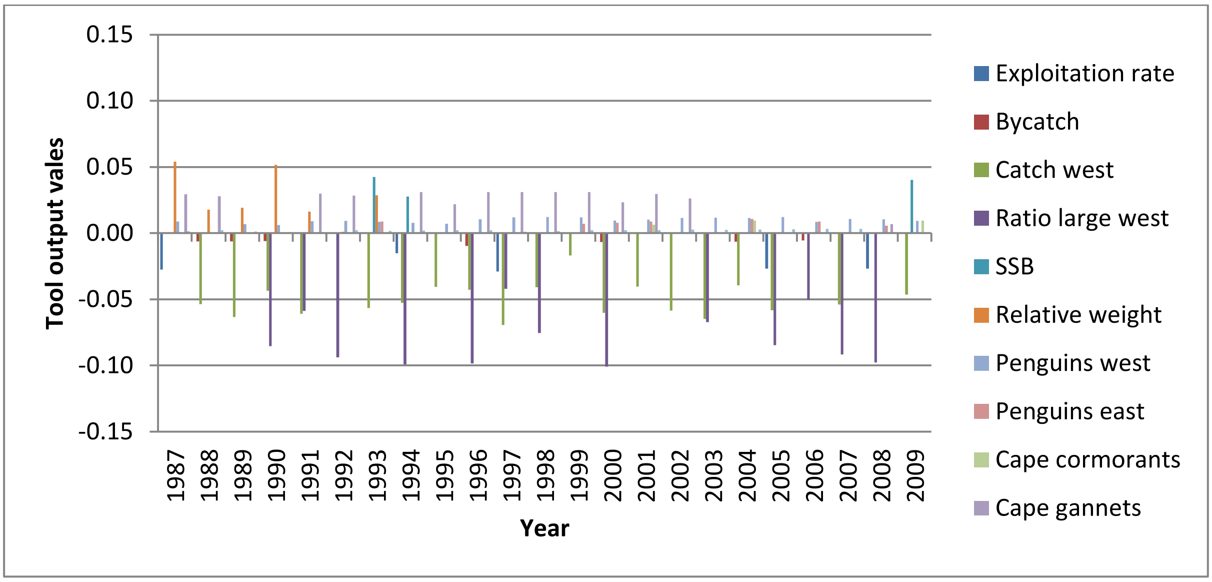


Figure 4.9: Absolute change in tool output value for the overall objective when one indicator is changed by (i) adding 5% to thresholds used to transform the indicator and (ii) adding 10% to thresholds used to transform the indicator while keeping other indicators at the baseline (expert-determined) values.

4.5. Discussion and conclusion

This chapter described the development of a knowledge-based tool to track the implementation efficacy of EAF in the South African sardine fishery. The tool focused on structuring the ecological well-being dimension of EAF by linking the ecological indicators identified in Chapter 3 to a suite of management objectives relating to broad pressure and state objectives for EAF in the sardine fishery. The knowledge-based tool is the result of a participatory modelling exercise to combine indicators and objectives for ecological well-being through the objectives' hierarchy. The ecological well-being of EAF is supported by long term monitoring and research in South Africa (see Moloney et al., 2004, Shannon et al., 2006 and 2010). While the ecological well-being dimension is important for implementation, all three dimensions of EAF are important. The sustainability a fishery system, however, cannot be achieved if any one dimension is dysfunctional.

To help to assess trends related to EAF objectives, indicators must be linked to societal goals and objectives (Garcia et al., 2000) and include reference points or threshold values to support interpretation (Degnbol, 2003, Degnbol and Jarre, 2004, Bundy et al., 2010). Identifying thresholds can be difficult, particularly where there is uncertainty in data quality, and in view of an often incomplete understanding of the complexity of the ecosystem (Paterson et al., 2007, Bundy et al., 2010). The threshold parameters selected for the indicators included in the knowledge-based tool were based on the best available scientific knowledge. The thresholds for the indicator 1^{+}SSB were model-determined through the OMP for small pelagic fishery (de Moor and Butterworth, 2008). Where hard data or quantitative model outputs were not available, expert knowledge was used to determine the thresholds.

The same experts who participated in identifying indicators in Chapter 3 were asked to identify threshold values for the indicators. Consensus among groups of experts helped ensure thresholds were acceptable and appropriate, in line with expert understanding of trends in the indicators over time. Expert knowledge provides a reliable estimate of threshold values in light of limited model or hard data information, and expert opinion has been shown to be more accurate than layman perceptions of risk (Burgman, 2005). The experts consulted have many years of experience and a strong understanding of the data and trends of the indicators selected. This helped to ensure that the best available scientific knowledge was accessed to use for threshold determination and their expert opinions for thresholds was therefore considered appropriate.

Stakeholders agreed with the thresholds presented to them and, as EAF requires stakeholder participation in decision-making, this was a valuable step in obtaining acceptance of the methods used in this chapter. The thresholds relied on expert opinion; as a result some uncertainty would be inherent (Burgman, 2005). The sensitivity analysis to changes in the threshold parameters found that, in general the objectives were robust to changes in thresholds. However, the indicators of spatially disproportionate fishing showed some sensitivity to changes in threshold parameters, which was not a surprising result as these indicators were developed specifically for use in the knowledge-based tool and the thresholds were based on limited experience. In addition, the indicators '*Relative weight of sardine*' and '*Breeding pairs of Cape gannets*' indicated some sensitivity to changes in the threshold values, but these indicators have a narrow range over the time series, and their variability over time was small. Any change in threshold value will have a larger effect on the output than for an indicator with a wide range of values over the time period examined. Despite these results, the indicators were generally robust to reasonable (5-10%) changes in threshold parameters, i.e. very few years showed a change in sign (indicating a change from positive to negative, or the other way round from one year to the next) when the indicators were transformed using different threshold values. These results did not raise concerns among stakeholders, it was appropriate to retain the expert-determined threshold values and use them as the basis of an overall evaluation of the EAF implementation efficacy of the ecological well-being of the sardine fishery over time.

Paterson et al. (2007) showed that transforming indicators using a piecewise transformation to a common scale was useful in interpreting the results of different indicators, as well as being easily communicable among stakeholders. The result of the transformation, the output value, can be interpreted as the percentage true, if a positive value is returned, or percentage false, if a negative value is returned, thus providing a transparent numerical output which can be communicated to stakeholders as a number from +1 to -1 or as a percentage true or false. Stakeholders who participated in building the knowledge-based tool reiterated the finding by Paterson et al., (2007), in that they agreed that transforming the indicators to a continuous scale from +1 to -1 was more appropriate and captured more of the complexity of the indicator than a point transformation of, for example 'good, okay and bad would do. However, it needs to be kept in mind that some stakeholders may find interpreting numerical outputs and figures more intuitive than others. Should other groups of stakeholders be included alternative methods or additional explanation may be required.

Indicator transformation allows for the direct comparison of trends over time and, in the context of this research, a way to combine and visualise the indicators to allow the overall interpretation of the effectiveness of EAF implementation in the sardine fishery was needed. The knowledge-based tool developed in this chapter provides an effective methodology for aggregating indicators and objectives for EAF implementation for the ecological-well-being of the South African sardine fishery.

Stakeholder feedback was essential in developing the approach used for aggregating indicators in this knowledge-based tool. The stakeholders were presented with alternative methods for combining the indicators, after which they agreed that for the second prototype the use of a simple mathematical function, the weighted mean, and standard software MS Excel would be most appropriate. Weights for the indicators and objectives were then determined through consultation with stakeholders. This exercise was invaluable in developing weights that reflected the current understanding and thinking around EAF in the sardine fishery, as well as building more understanding of the issues relating to EAF implementation among a larger group of stakeholders than had previously been consulted. The feedback and questions fielded during the meetings enabled stakeholders to gain greater understanding of the knowledge-based tool and development process and has resulted in strong agreement on the relative importance of the indicators and objectives in the hierarchy. Several "*Aha!*" moments among individual stakeholders were observed during the meetings. During the meetings, I observed a few stakeholders demonstrating a change in their understanding of the interactions between indicators and/or an improved understanding of the issue an objective addressed. These observations were not formally recorded at the time but have helped to underpin the basis for Chapters 5 and 6.

The exercise in selecting weights for the indicators and objectives of ecological well-being in the sardine fishery was an interesting and valuable one, as the weight selection was inherently subjective. Stakeholders were asked to select weights based on their expert knowledge and with information on previously selected weight scenarios. While the final suite of weights selected for use in building the knowledge-based tool were based on consensus among the stakeholders consulted, the selection of weights reflected individual stakeholder's interests and priorities. For example, the seabird ecologists chose to weight the seabird objectives higher than the other stakeholders did. Weight selections could have been for methodological reasons (for example, redundancy, and unequal uncertainty between indicators) or policy reasons (for example, inflating the importance of an indicator to keep it on conservation or management agendas) (Rice and Rochet, 2005). It is assumed that the weights selected in this iteration of tool development were for methodological reasons, as justified in section 4.4.3. The rationale for weight selection should be made explicit. Careful consideration and questioning over the rationale for the weights selected help differentiate between weights chosen for methodological reasons and those selected for policy reasons.

The objectives were robust to changes in weight. While applying different weights in the sensitivity analysis affected the numerical output of the objectives, under most scenarios a similar pattern was maintained and a change in the weights did not result in a change in the sign of the output values. In addition, the variance between scenarios was generally very low. Therefore, a change in weight would not drastically alter the knowledge-based tool output through the weighted means analysis for pressure, state and overall objectives. This was useful in the context of weight selection by stakeholders and helped to show that a similar pattern can be observed regardless of whether weighting more heavily towards sardine or towards ecosystem indicators. It is unlikely that information would be lost completely through choosing one weight scenario over another. However, some information may be lost if the overall objective is taken on its own, without reference to the pressure and state objectives. Under all the weight scenarios the overall objective reflected the same general pattern as the pressure objective, and showed less influence by the state objective. Some detail of the state objective was therefore lost in the overall objective scenarios. Careful consideration on how the results of the knowledge-based tool are communicated should include descriptions of the conditions, that is, the indicator performance and weight scenario which resulted in the tool output observed for a given period or year.

It is important that the knowledge-based tool be transparent and defensible, and ensures stakeholder buy-in to the processes. The knowledge-based tool presents the detail of input data and calculations in a visible manner. This has resulted in aiding the communication and understanding of the methodology among stakeholders and helps move towards a knowledge-based tool that can be useful to the fishery managers. Aggregating indicators using a weighted mean equation is just one of several methods for combining indicators. The selected aggregation method met the requirements of being simple to understand and readily reproducible in MS Excel. However, the visualisation of the results of aggregating indicators provided a snapshot trend over time and doesn't easily identify indicator(s) contributed to the outputs from these combined evaluations.

Stakeholders agreed that the use of a weighted mean to combine indicators was appropriate for their level of understanding of EAF; however, different groups of stakeholders may prefer different methods of combining the indicators - for example, less numerical ones or visualisation (other than x-y plots) of the results in the knowledge-based tool. At the end of a meeting with EAF-SWG stakeholders, participants recommended that the presentation of the knowledge-based tool be refined to incorporate different stakeholder needs, with the group hypothesising that different stakeholders may prefer alternative methods of visual representation of the tool.

The function of indicators and expert systems in improving the accountability, transparency and effectiveness of management among stakeholders is widely documented (Belton and Stewart, 2002, Goodwin and Wright, 2004, Paterson et al., 2007, Rochet et al., 2007, Turnhout et al., 2007). To effectively achieve this goal, these tools need to be communicated efficiently. Chapter 4 builds on the process of developing the knowledge-based tool presented here; incorporating stakeholder recommendations to better communicate and interpret the tool outputs among stakeholders and other potential users of the tool.

Chapter 5

The communication challenge: Presenting outputs of the knowledge-based tool to stakeholders

5.1. Introduction

A knowledge-based tool for assessing the ecological well-being dimension of EAF in the sardine-directed fishery has been developed in Chapters 3 and 4 of this thesis. This tool links a suite of ecological indicators to management objectives presenting a snapshot over time of the ecological well-being of the sardine fishery in terms of the pressures exerted by the sardine fishery on the ecosystem and the state of the southern Benguela ecosystem. It is envisioned that the knowledge-based tool can be used by stakeholders and decision-makers as a strategic planning tool to track the implementation of EAF in the fishery, communicate the complexity, trade-offs and uncertainties relating to implementing an EAF and guide thinking around the issues of EAF in the fishery among stakeholders. To take this further and additional round of stakeholder engagement was considered important (EAF-SWG, 2012). In particular, questions arose around whether the tool outputs would be effective in supporting communication among stakeholders and between the EAF-SWG and fishery managers as the intended end-users of the tool.

Communication among stakeholders is considered an important outcome of the knowledge-based tool. The literature widely acknowledges the role that expert systems and other MCDA tools have in supporting the communication of complex, multi-criteria decision problems (Belton and Stewart, 2002, Goodwin and Wright, 2004). These tools offer a framework in which to develop a common language which can be used to communicate between stakeholders or decision-makers (Belton and Stewart, 2002). Similarly, indicators as a tool to support EAF implementation have been shown to improve communication, transparency, effectiveness and accountability of management among stakeholders (Garcia et al., 2000). By presenting a synthesis of indictors which communicate the progress in meeting objectives set by stakeholders, the knowledge-based tool has the potential to communicate the progress (or lack thereof) being made towards EAF implementation in the sardine.

Schiller et al. (2001), Chess et al. (2005) and Potts (2006) emphasise the importance of following through with this step; however, effective communication is often neglected in practice (Grey and Wiedemann, 1999, Chess et al., 2005, Potts, 2006). Exploring ways of communicating the outputs of the knowledge-based tool among stakeholders and the general public is therefore considered the final step in the tool development process in this thesis.

The challenge in communicating indicators and indicator frameworks among stakeholders is widely documented in the literature (Hammond et al., 1995, Garcia et al., 2000, FAO, 2003, Potts, 2006, Reed et al., 2006, Shields et al., 2006, Mackinson et al., 2011). The FAO guidelines for an effective EAF management plan emphasise the need for a communication strategy to be developed which includes opportunities to regularly share the progress of indicator system development with stakeholders and creates the space to allow communication of the process and outcomes with higher level fisheries management (Garcia et al., 2000). Shields et al. (2006) outline what they call a 'communication challenge' when developing an sustainability indicators (and by inference, indicator frameworks which synthesise and communicate progress made in the indicators developed). These authors highlight the difficulty in designing indicators to be both relevant to the problem being addressed and meaningful to the intended audience. It is important to consider the needs of the audience of the models being developed. This can be done by considering how the visualise, report outputs to help communicate the information to intended audiences, such as decision-makers (Potts et al., 2006). Effective communication of outputs can therefore help to improve attitudes towards information, enhance relationships between stakeholders and support in decision-making processes (Sheilds et al., 2006, Mackinson et al., 2011).

The knowledge-based tool development process was informed by mediated modelling approaches. Mediated or participatory modelling supports the inclusion of stakeholders in each step of the modelling process. A key outcome of successful mediated modelling is the enhanced communication, both in the model as a communication tool and through improving communication and creating shared understanding of the system or problem being modelled between stakeholders (van den Belt, 2004), Therefore, during the knowledge-based tool development process, additional time spent with stakeholders in improving the visualisation and reporting of the model (or tool) outputs is a useful step in maintaining the participatory nature of this process and as a result, accessing the perceived benefits of participation.

The aim of this chapter is to gain insights from stakeholders on how to improve the communication of the knowledge-based tool outputs. The same questions were used for all focus groups and addressed two key questions:

i. Would the same output be acceptable to all stakeholders?

ii. If the output is acceptable, would a change in the visual presentation or language used to report the tool outputs help to facilitate understanding? If the selected presentation style is considered inappropriate by the stakeholders, what alternative model structures would be more useful in meeting the stakeholders' requirements?

Along with these key questions, the aim of the meetings was to focus on producing a suite of suggested changes to the tool outputs that included (i) how to best display the knowledge-based tool outputs, (ii) how to best describe the outputs using words and colours, and (iii) how much detail in the tool is meaningful to the stakeholders. The suggested changes and a discussion on the results of focus groups are presented in this chapter.

5.2. Methods

A series of focus group meetings were held to address the aim of this chapter. Focus groups create the space to bring stakeholders with similar characteristics into a focused discussion (Krueger and Casey, 2009). Grouping stakeholders together allows for discussion and the generation of new ideas specific to the requirements of particular groups (Krueger and Casey, 2009). Paterson et al. (2010) used focus groups to identify stakeholder perspectives when developing objectives for the human dimension of EAF in the South African small pelagic fishery. This method proved useful as the first step in facilitating meaningful interactions among stakeholders (Paterson et al., 2010).

5.2.1. Stakeholders

Stakeholders identified to participate in this process included members of the EAF-SWG, PEL-SWG and other experts who had been consulted in developing the first iteration of the knowledge-based tool, as well as individuals with an interest in and knowledge of the South African sardine fishery and related ecosystem issues who had not been directly involved in the development process. Stakeholders were divided into four focus groups, selected according to their professional interests and responsibilities. These groups were: EAF biologists, Sardine biologists, Small pelagic fishery management and Civil society and seabirds. Table 5.1 presents a list of stakeholders who participated in the different focus groups and their professional affiliation, as well as membership status to the EAF-SWG and SWG-PEL. This table also includes a list of stakeholders who were invited to participate but did not attend the meeting.

The stakeholders invited to participate in the EAF biologists' focus group were familiar with and active in research relating to EAF objectives in the small pelagic fishery and most were members of the EAF-SWG. The stakeholders invited to participate in the Sardine biologists' focus group work with small pelagic species through direct research and monitoring or in creating advice for management, and most were members or observers in the SWG-PEL. The Civil society and seabirds focus group consisted of a more mixed group of stakeholders from academic research, conservation NGOs and management agencies, who were interested in implementing an EAF in the sardine fishery and particularly concerned with the health of top predators linked to the small pelagic fishery. Stakeholders who worked in resource management of the small pelagic fishery were invited to participate in the small pelagic fishery management focus group.

All identified stakeholders were contacted by email and invited to attend a specific focus group meeting. The invitations outlined this thesis and the expectations of the research, and stakeholders were asked if they would like to participate in a focus group and indicate which of a selection of three dates and times would suit them. A copy of the email sent to the stakeholders is attached in Appendix 3. Follow-up emails and telephone calls were used to ensure that all stakeholders were aware of the invitation to participate. Confirmation emails were sent to stakeholders who were able to attend the meetings. Thank you letters were emailed to stakeholders who participated in a focus group, this email provided stakeholders with an additional opportunity to share their thoughts and ideas on what was presented and discussed at the focus group meeting.

Table 5.1: List of all stakeholders who participated in the focus group meetings. The stakeholders invited but unable to attend the meetings are included.

Name	Institution/Affiliation	Role in SWG-PEL	Role in EAF SWG
At all meetings			
Emily McGregor Facilitator	UCT SARChI Marine ME&F. PhD student		
Carl van der Lingen	DAFF Fisheries research	Member	Chair
Sardine fishery focus group			
Present at meeting			
Janet Coetzee	DAFF Fisheries research	Chair	
Jan van der Westhuizen	DAFF Fisheries research	Member	
Yonela Geja	DAFF Fisheries research	Member, convener	
Ashok Bali	DAFF Fisheries research	Member	
Sobahle Somhlaba	DAFF Fisheries research	Member	
Invited but did not attend			
Fannie Shabangu	DAFF Fisheries research	Member	
Nandipha Twatwa	DAFF Fisheries research	Member	
Mzwamadoda Phillips	DAFF Fisheries research	Member	
Kanakana Mushanganyisi	DAFF Fisheries research	Scientific observer	
EAF biologists focus group			
Present at meeting			
Astrid Jarre	UCT SARChI Marine Ecology and Fisheries	Scientific observer	Member
Lynne Shannon	UCT SARChI Marine ecology and Fisheries	Scientific observer	Member, previous Chair
Larry Hutchings	DEA Oceans & Coasts	Scientific observer	Member, previous Chair
Tracey Fairweather	DAFF Fisheries research		Scientific observer
Henning Winker	UCT Postdoctoral fellow		
Herman Oosthuizen	DEA Oceans & Coasts	Member, Island closure task team Chair	Member
Invited but did not attend			
Rob Crawford	DEA Oceans & Coasts	Scientific observer	Member, previous Chair
Newi Makhado	DEA Oceans & Coasts	Scientific observer	Member
Steve Kirkman	DEA Oceans & Coasts		Member
Tarryn Lamont	DEA Oceans & Coasts		
Dawit Yemane	DEA Oceans & Coasts		Member
Sven Kerwath	DAFF Fisheries research		Scientific observer
Civil society and seabirds focus group			
Present at meeting			
Alice Johnson	WWF South Africa	Scientific observer	
Christina Moseley	BirdLife South Africa	Scientific observer	
Lauren Waller*	Cape Nature, UCT ADU Honorary Research Associate,	Scientific observer	
Richard Sherley	UCT Postdoctoral Fellow		
Invited but did not attend			

Table 5.1 continued

Name	Institution/Affiliation	Role in SWG-PEL	Role in EAF SWG
Samantha Petersen	WWF sustainable fisheries		Member
Ross Wanless	BirdLife South Africa		
Small pelagic fishery management focus group			
Present at meeting			
Johan de Goede	DAFF Resource management	Member	
Invited but did not attend			
Craig Smith	DAFF Resource management		
Pheobius Mullins	DAFF Resource management		
Sassa Pheena	DAFF Resource management		

*L. Waller was invited to participate in this focus group in her role as an Honorary Research Associate with the Animal Demography Unit (ADU) in the Department of Biological Sciences, UCT.

5.2.2. Focus groups

Seven stakeholders participated in the EAF biologists' focus group; this was the first focus group meeting held. Six stakeholders participated in the Sardine biologists' focus group and five participated in the Civil society and seabirds focus group. Only one stakeholder in the Small pelagic fishery management group could attend a meeting. As there was only one manager, an interview was conducted with them following the same protocol and discussion path as the focus groups.

Focus group meetings with stakeholders were held between July and September 2012, except for the meeting with fishery management stakeholders which was held in early 2013. The approach followed in planning and structuring the focus group meetings was informed by Krueger and Casey (2009). The EAF biologists, Sardine biologists and Small pelagic fishery management meetings were held at the DAFF offices in Cape Town, while the Civil society and seabirds focus group meeting was held in the Zoology Department at UCT. Each meeting lasted approximately one and half hours and was recorded using a small voice recorder placed centrally in the room. It was necessary to limit the time spent in the meetings. As the stakeholders all have full-time positions within their organisations they are limited by their professional time commitments. By providing a time limit it was easier to ensure stakeholders could attend the meeting. I facilitated each focus group and received support from Dr Carl van der Lingen in the role of co-facilitator.

The structure of the meeting (presented as a flow diagram in Figure 5.1) was kept the same for all focus groups. A PowerPoint presentation was used to guide the discussion through the meetings (see Appendix 4). At the start of each focus group meeting a short description of the background and motivation for the research was provided, followed by a presentation of the indicators, thresholds, weights used in the knowledge-based tool. Following this, the three key questions relating to improving the communication of the model outputs were asked of the stakeholders: (i) how to display the tool, (ii) how to describe the outputs; and (iii) how much detail is meaningful. The structure of the PowerPoint presentation helped to guide discussion with the stakeholders and assisted in answering the key questions. Comments, discussion and questions for clarity were welcomed at any point during the presentation.

As time was limited in these meetings, the parking lot allowed issues on topics not covered in the meeting to be aired and noted for follow up at a later date, but these were not discussed in the focus group meetings. The parking lot section of the focus group presentations allowed stakeholders time to raise any issues, concerns and new information on the underlying data used in the knowledge-based tool.

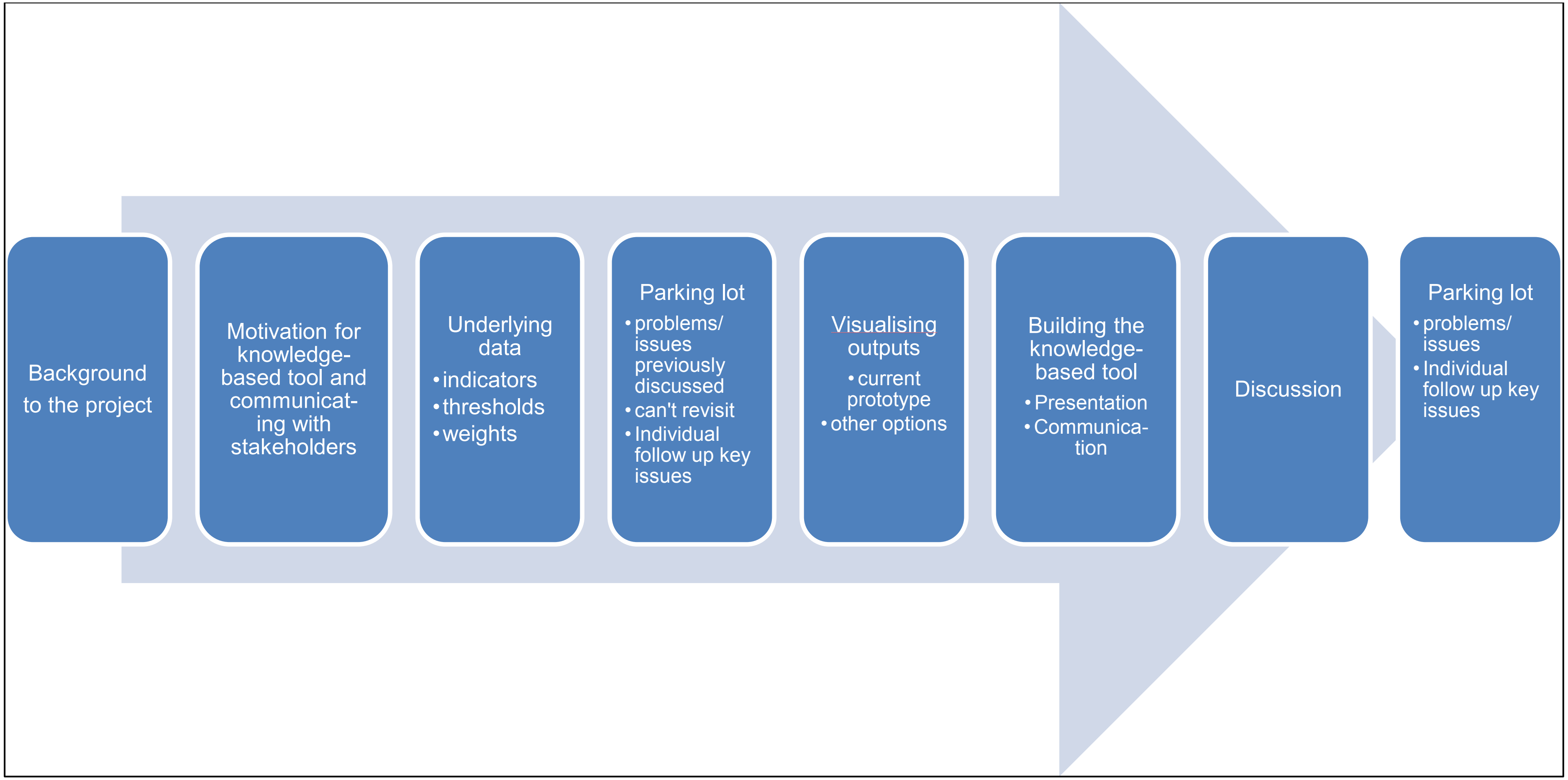


Figure 5.1: The structure followed in the PowerPoint presentation given at each focus group meeting.

The knowledge-based tool and the model outputs developed in Chapter 4 were presented to the focus groups in the following order:

i. A snapshot of the annual output from the tool using 2004 as an example, shown as both horizontal and vertical bar charts (Figure 5.2). These figures were most similar to previously published outputs (Paterson et al., 2007, Jarre et al., 2008), and stakeholders were asked which figure they preferred and why.

ii. The same figure was presented to the stakeholders again (either horizontal or vertical bar chart depending on stakeholder response to question in part 1) and additional text was supplied to help with interpreting the figure (Figure 5.3). The stakeholders were asked if they thought anything should be changed to improve interpretation and visualisation of the output.

iii. Stakeholders were then asked to provide input into the choice of language used for interpreting the outputs and the selection of appropriate colours for the bars (an example of colours and words used to interpret the figure is presented in Figure 5.3).

iv. A figure showing the trend over time for the pressure and state objectives and the overarching ecological well-being objective were then presented to the stakeholders (Figure 5.4). Stakeholders were asked whether they preferred being presented with an output showing the annual snapshot (Figure 5.2) or a trend over time (Figure 5.4), and asked if they had any suggestions on how to improve the presentation of these figures.

v. Stakeholders were given the opportunity to suggest alternative ways to visualise the outputs.

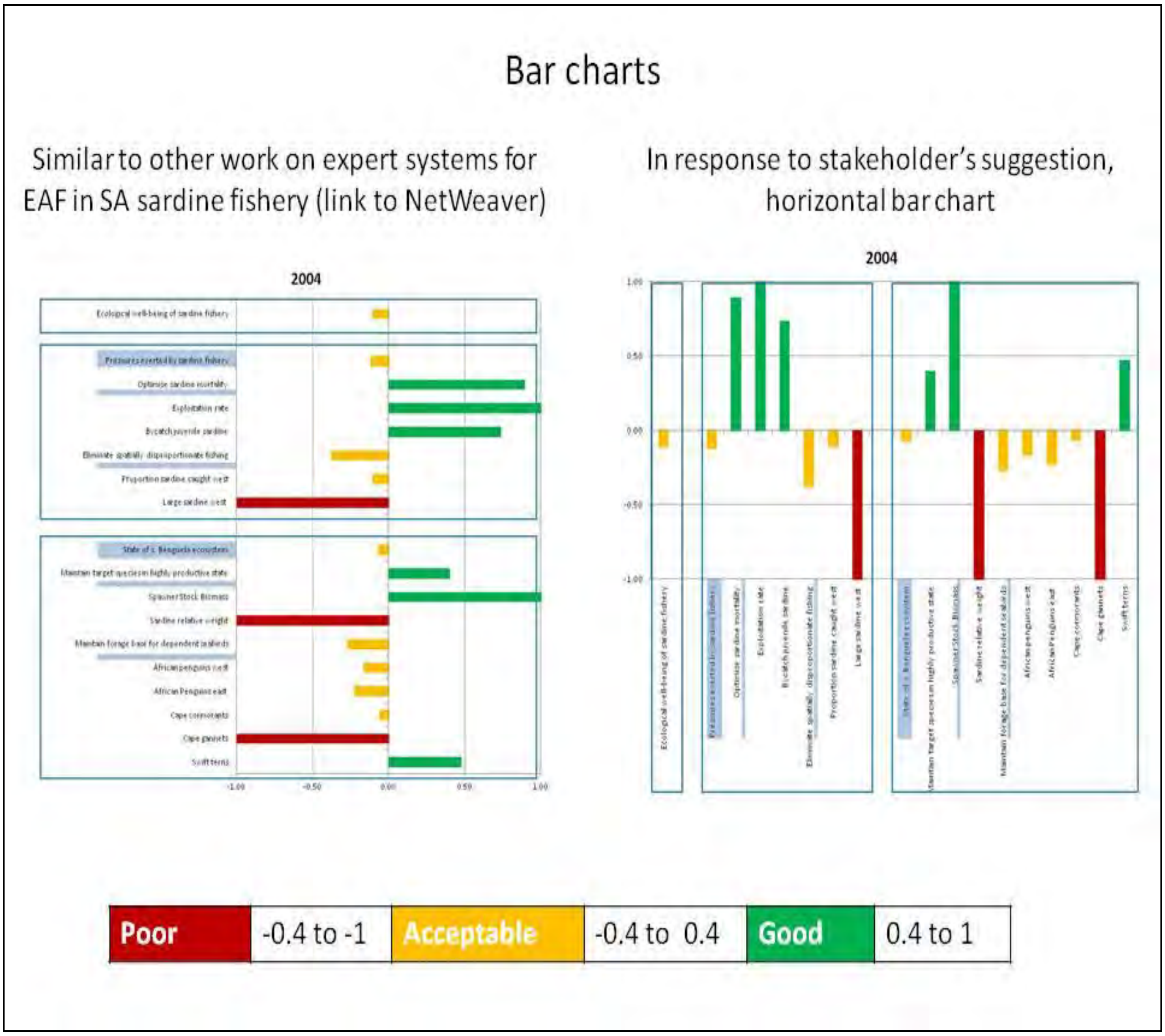
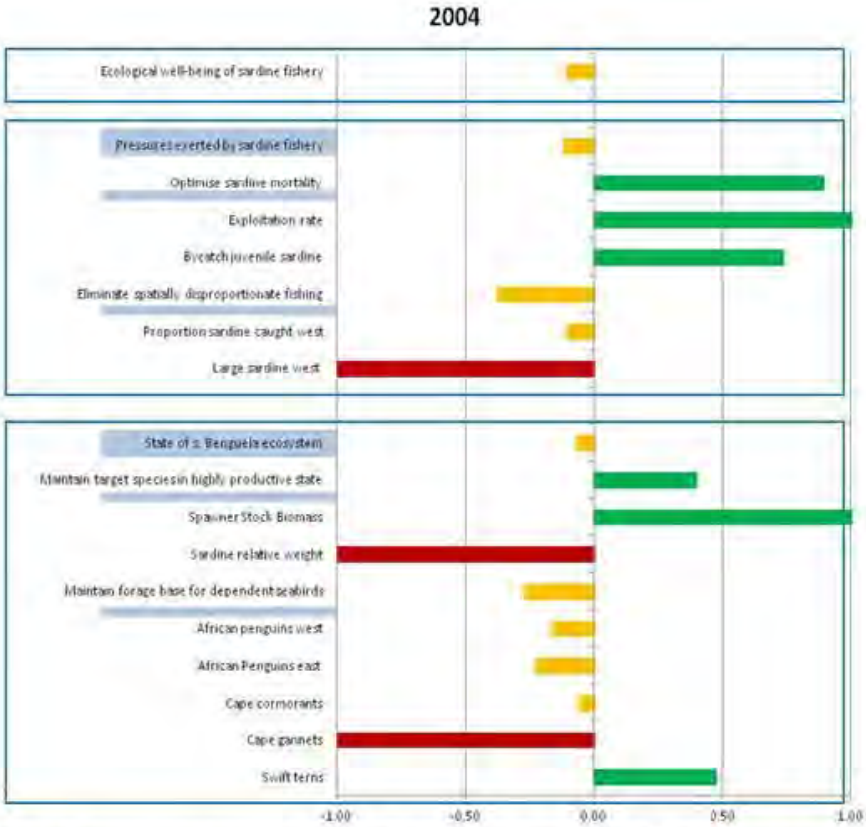


Figure 5.2: The knowledge-based tool outputs presented as a snapshot of a single year. The option of a vertical (left) or horizontal (right) bar chart was offered to stakeholders in the focus group meetings. The year 2004 was selected as a representative year in the time series applied in the tool development process.



In 2004 the pressures exerted by the sardine fishery were 'acceptable'.

This was because:
(i) Sardine mortality is optimised, optimal exploitation rate was reached or exceeded and low numbers of juvenile sardine were caught (these indicators fall above 0.4 'good' definition)
(ii)The amount of spatially disproportionate fishing is 'acceptable' trending towards poor as the number of sardine caught west of Cape Agulhas was not proportionate to the population west of CA, i.e. more sardine were caught than where available on the west coast, and the proportion of large sardine caught west of Cape Agulhas was equal to or higher than a ratio of 1:1 (truth value = -1).

Poor	-0.4 to -1	Acceptable	-0.4 to 0.4	Good	0.4 to 1

Figure 5.3: The knowledge-based tool outputs presented as a vertical bar chart presenting a snapshot of a single year. Including an explanation of the knowledge-based tool outputs for the year 2004.

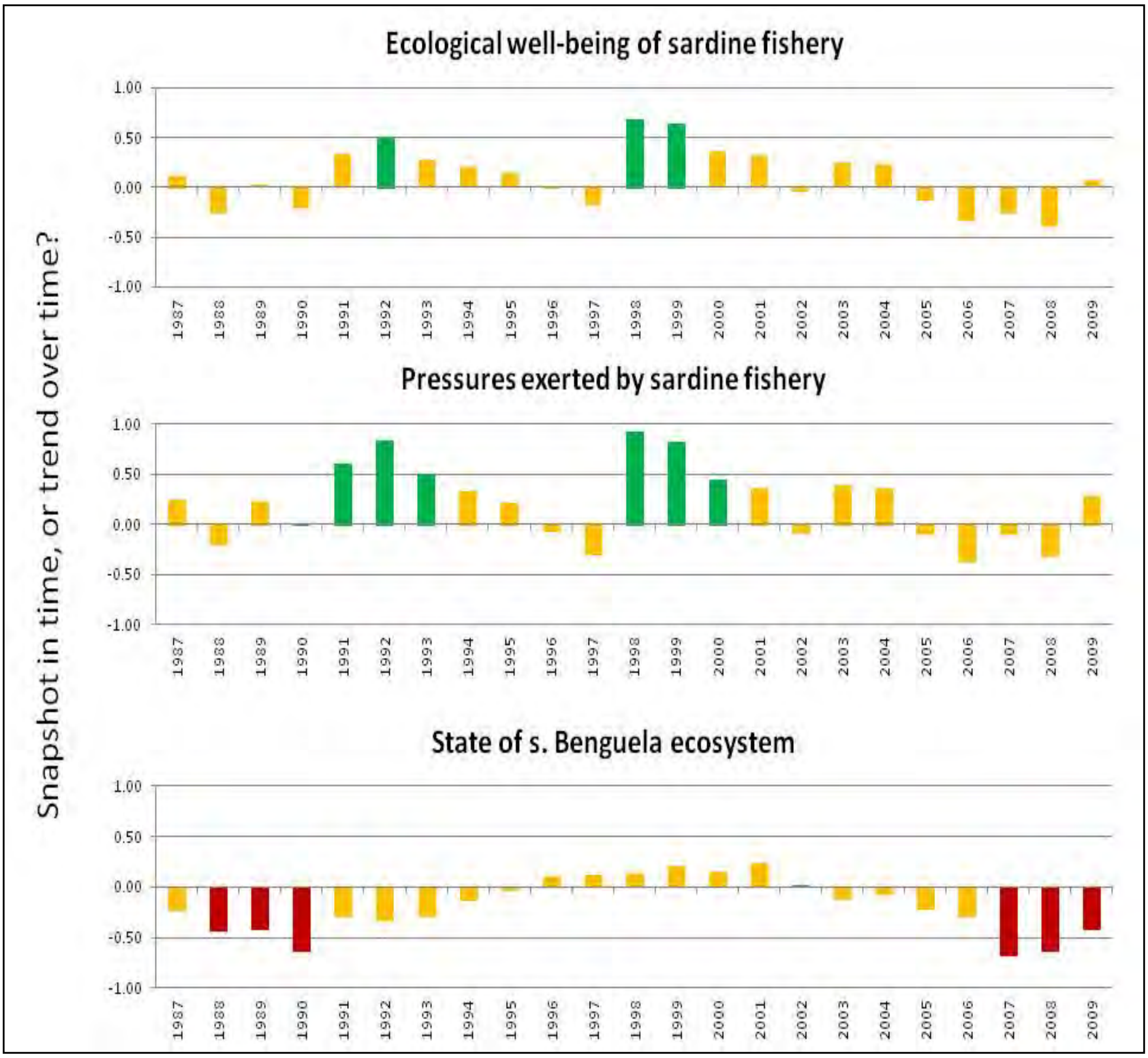


Figure5.4: The knowledge-based tool outputs for the time period 1987-2009 presented in the focus group meetings. Presented separately for the broad objectives of pressure and state. The combined analysis of these objectives results in an assessment of ecological well-being in the South African sardine fishery, presented in the top panel.

5.2.3. Data analysis

Audio recordings and transcripts from each meeting were analysed to identify any themes or subthemes arising out discussions with stakeholders in the focus groups. The identified themes reflected both how to communicate the outputs of the knowledge-based tool among stakeholder groups and the more technical changes required to improve the tool outputs. Each suggestion for technical changes to the model outputs was considered and the figures changed to reflect these suggestions. From the themes identified in each focus group the major themes shared by all four focus groups were compared to identify the similarities and differences in these themes across the focus groups. The length of time each focus group spent discussing the themes was calculated from the audio recordings of each focus group.

5.3. Results

5.3.1. Challenges in communication: Key themes in focus groups

Three themes were identified from discussions in the focus groups: Visualising the tool, Data and Audience. These reflect the discussions facilitated through the structure of the presentation given each focus group.

Visualising the tool	Links to key questions asked in the presentation and the communication of the knowledge-based tool outputs as presented in the focus groups. Including both the practical changes needed to improve presentation and readability of the outputs, and discussions on the level of detail and structure of outputs as a whole.
Data	Draws on the discussion on the underlying data used to build the tool and any stakeholder concerns or issues presented in the parking lot during the presentation.

Audience Considers stakeholders' discussion on the intended audience for the tool, and the result of this on the choice of graphical presentation of the tool.

The percentage of time spent on the key discussion points was calculated for each focus group meeting, and these are presented in Figure 5.5. Meetings were run for approximately the same length, around 90-105 minutes. The presentation content refers to the time that I spent talking through the PowerPoint presentation and explaining the tool outputs, and clarifying any questions on the presentation content. I spent approximately the same amount of time presenting content to stakeholders in the EAF biologist, Sardine biologist and Small pelagic fishery management focus groups (39-44%). Whereas less time was spent on this in the Civil society and seabirds focus group, where the majority of time was spent on discussing how to visualise the knowledge-based tool outputs (46%).

The EAF biologist group spent just over a quarter of the meeting time discussing how to visualise the tool (26%) and the Sardine biologist group spent 22% of the meeting considering how to graphically present the tool. The Fishery manager was less concerned about the way the tool was presented, spending just 13% of the meeting time suggesting improvements to the knowledge-based tool. The time spent considering underlying data in the parking lot section of the meetings were similar for the Fishery manager, Sardine biologists' and EAF biologists' focus groups (see Theme 2, below). The Fishery manager spent a little more time considering underlying data; however, the type of discussion had on data during this meeting was different to that in the Sardine and EAF biologists' focus groups (see Theme 1).

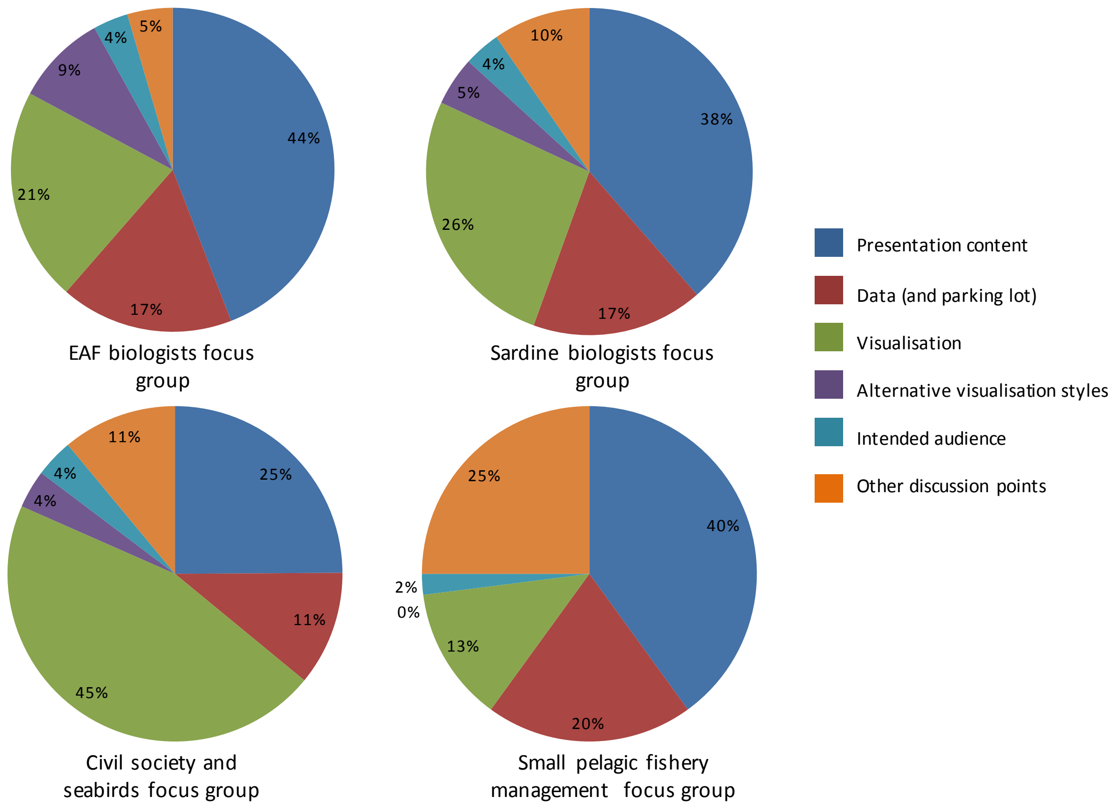


Figure 5.5: The time spent in each focus group on key themes or discussion points. The time allocations are displayed as a percentage of the meeting time

Very little meeting time was spent discussing the intended audience for the tool in all the focus groups (approx. 5%). This was not something directly asked to the stakeholders during the focus groups and hence there was little discussion. Despite this, insights into the audience considered for the use of the knowledge-based tool was useful in understanding the way stakeholders discussed the visualisation of the tool and informed their choices of alternative presentation styles (see Theme 3).

Theme 1: Visualising the tool

The topic of visualising and communicating the knowledge-based tool took up most of the meeting time once the initial presentation had been given. To determine if the tool outputs presented would be acceptable to stakeholders and what practical changes to the outputs could be implemented to improve the communication thereof among the stakeholder groups was the key aim of the meetings. Stakeholders were therefore asked to discuss and consider the practical changes that could be done to improve how the annual snapshot of the tool was presented. Selecting a graphical presentation and language that is intuitive and easy to understand was an important outcome of these meetings. Table 5.2 provides a summary of the key changes to the graphical presentation of the tool outputs, the order to present the outputs in and any alternative presentation options offered.

All four focus groups indicated a preference for the horizontal bar chart (see Figure 5.3). They considered this figure to be more intuitive to interpret as the text was easier to read and the values could be read from positive to negative.

Civil society/seabirds	*"We are used to reading graphs."*
Sardine biologists	*"The graphic is not a problem, I don't mind which way it goes. But the text is easier to read from left to right."*
EAF biologists	*"I think I like the right hand one [figure] just because it's like we learnt at school everything above that zero line is positive and everything below the line is negative. So it's very easy."*
Fishery manager	*"This [figure] makes sense to me."*

Table 5.2: A summary of the stakeholder discussions on visualising the knowledge-based tool. For each focus group, the prefered graphical presentaiton of the tool, the order of presenting the tool outputs, and the level of detail considered appropriate by the stakeholders are listed. Any alternative presentaiton styles suggestd by the stakeholders are included.

Focus group	Graphical presentation style	Order of presenting the tool outputs	Level of detail presented	Alternative presentation styles
EAF biologists	Horizontal bar chart	Display the outputs in a pyramid. Start general with the time series for the overarching Ecological well-being objective, then State and Pressure, then annual outputs.	Provide both a figure and text allowing reader to decide how much detail to follow.	Bi-plot Table
Sardine biologists	Horizontal bar chart	Delimit the hierarchy using boxes or staggering levels.	No comments	Gantt chart
Civil society and seabirds	Horizontal bar chart	Delimit the hierarchy by staggering the levels and using solid lines to divide objectives from indicators Make area proportional to weight.	Present the tool outputs separately, each objective on own in a year. Increase detail as go into report, general to specific. Allow the audience to choose how much want to take away from report.	Table
Small pelagic fishery management	Horizontal bar chart	No suggestions for the order of presentation.	Switch between the overall picture, the definition of objective/indicator and the time series of individual indicators. Place clear explanations of each indicator and objective into text.	No comments

Three of the four focus groups recommended that the hierarchy of objectives and indicators should be more defined (Table 5.2). The stakeholders suggested that delimiting the hierarchy with boxes, or staggering the text in the figure, would ease interpretation of the bar chart.

Sardine biologists	*"The message we get is that all bars reflect the same thing, with no weights or levels."*
Civil society/seabirds	*"To me it just looks like a list."*

To some extent, all focus groups agreed that the outputs should first be presented at the broad objective level, and then to include more detail. This would allow the audience to decide what level they would like to access. Presenting outputs as a pyramid would help distinguish objectives and better match the hierarchical framework used to develop the tool. This order was agreed to by all focus groups.

When asked if any other style of visual presentation of the outputs would be useful to explore, the EAF biologist focus group suggested a bi-plot and table as alternative styles, and the Civil society and seabird focus group also suggested a table format. A stakeholder in the Sardine biologist group recommended exploring the use of Gantt Charts, commonly used in project management to assist with staggering of the rows in a table.

A bi-plot presents how the objective (pressure and state objectives combined to value for the ecological well-being of the fishery) changed over time to show progress towards meeting an agreed upon position for well-being and EAF in the fishery, for example, falling into the 'green' box for Pressure and State objectives. The idea behind using a bi-plot to provide a visual measure of how objectives are doing in terms of reaching a good situation (reaching the good threshold defined by experts) is valuable in the context of communicating progress over time and providing a single visual output of the outcome of the knowledge-based tool. In practice, however, the design of a bi-plot for the ecological well-being dimension would not take into account the weights assigned to the state and pressure objectives. Weights are an important aspect of the knowledge-based tool, as they allow for balancing competing objectives in light of uncertainty and poor data quality or availability and represent relative priorities or importance by stakeholders. While the sensitivity analysis in Chapter 4 suggests the knowledge-based tool is relatively robust to changes in weight the implication of weight selection for communicating trade-offs and uncertainties in data among stakeholders is important and would be lost if a bi-plot were to be used.

If a bi-plot were to be designed to take weight into consideration, supporting text to help the reader interpret the figure would need to be developed as it is a more unusual form for presenting multivariate data. The message presented would be different from the stock-assessment related bi-plots which show the trajectories of biomass versus fishing mortality. This has the potential to confuse discussions rather than facilitate mutual understanding.

Creating a table to present tool outputs was suggested as an alternative presentation style in the Sardine biologists' and Civil society and seabirds focus groups. An example of how the knowledge-based tool can be visualised in this way is presented in Table 5.3. Whilst large and cumbersome to the eye, a table is an effective way of presenting all of the data in one place. It can take into account the hierarchy of objectives by staggering the text, and it can represent the weights selected by changing the size of the rows. Colour coding the years will also help to present trends over time without needing to refer to the actual values. The output values are provided to give more detail should the audience want this. Tables may be more familiar to readers not comfortable with graphs. Here the table is colour coded in line with stakeholder suggestions as reported in Table 5.5 (see section 5.3.4). The objectives of pressure and state are placed in separate tables. The weights for each objective and indicator are provided at the end of the table.

Much of the discussion among the stakeholders in this theme has resulted in practical changes implemented to improve the presentation of the tool. These suggestions and resulting improved knowledge-based tool outputs are presented in section 5.3.2.

Table 5.3: The knowledge-based tool outputs presented as a table. This was suggested by some stakeholders as an alternative to the bar chart for displaying the knowledge-based tool outputs. The outputs of the tool, for indicators and the objectives, are presented in colours representing the ranges of output values given in the bar below the figure.

Management objective	Indicator	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Ecological well-being of sardine fishery		Yellow	White	Yellow	White	Yellow	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Green	Yellow	Green	Yellow	Yellow	Yellow	Yellow	Yellow	White	White	Yellow
Pressures exerted by the sardine fishery		Yellow	Yellow	Yellow	Yellow	Green	Green	Green	Yellow	Yellow	Yellow	Yellow	Green	Green	Green	Green	Yellow	Green	Green	Yellow	Yellow	Yellow	Yellow	Green
Optimise sardine mortality		Yellow	Red	Red	Red	Green	Yellow	Yellow	Red	Yellow	Red	Orange	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Yellow	Orange	Orange	Yellow	Green
	Exploitation rate	Red	Red	Red	Red	Green	Green	Green	Red	Green	Red	Red	Green	Green	Green	Green	Green	Green	Green	Red	Red	Red	Red	Green
	Bycatch juvenile sardine	Green	Orange	Orange	Orange	Green	Red	Red	Red	Red	Red	Green	Green	Red	Red	Green	Red	Red	Green	Green	Green	Green	Green	Green
Eliminate spatially disproportionate fishing		Green	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Yellow	Green	Green	Green	Green	Yellow	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow
	Proportion sardine caught WoCA	White	Red	Yellow	Orange	Yellow	Green	Yellow	Green	Orange	Orange	Red	Green	Green	Yellow	Orange	Red	Yellow	Orange	Green	Red	Red	Red	Orange
	Ratio of large sardine	White	Red	Red	Yellow	Green	Orange	Red	Red	Green	Orange	Green	Green	Green	Red	Red	Green	Green	Red	Yellow	Green	Red	Yellow	Green
State of the southern Benguela ecosystem		Orange	Orange	Orange	Red	Orange	Orange	Orange	Orange	Orange	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Orange	Orange	Orange	Orange	Orange	Red	Red	Orange
Maintain target species in highly productive state		Orange	Red	Red	Orange	Red	Red	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Red	Orange
	1^+SSB	Red	Red	Red	Red	Red	Red	Yellow	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Red	Yellow
	Sardine relative weight	Green	Orange	Orange	Green	Orange	Red	Yellow	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red
Maintain forage base for dependent seabirds		Orange	Orange	Orange	Orange	Orange	White	Orange	Orange	Orange	Orange	Orange	Orange	White	White	Yellow	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange
	African penguins west	Red	Red	Red	Red	Red	Orange	Red	Red	Red	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Green	Orange	Orange	Orange
	African Penguins east	White	White	White	White	White	White	Green	White	White	White	White	White	Yellow	Green	Green	White	White	Orange	Red	Red	Red	Red	Red
	Cape cormorants	White	Green	Red	Red	Green	Green	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	White	Red	Red	Red	Red	White
	Cape gannets	Green	Yellow	Green	Red	Green	Yellow	Red	Green	Green	Green	Green	Green	Green	Green	Green	Orange	Red	Red	Red	Red	Red	Red	Red
	Swift terns	Orange	Orange	Red	Red	Red	White	Orange	Orange	White	White	Red	Orange	Orange	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Green	Green	Green	Green

Colour	Red	Orange	White	Yellow	Green
Output number	-1 to -0.50	-0.49 to -0.10	-0.09 to +0.09	+0.10 to +0.49	+0.5 to +1
Interpretation	**Bad**	**Poor**	**Neutral**	**Acceptable**	**Good**

Theme 2: Data

The data underlying the indicators and the objectives used to build the knowledge-based tool were always an area of discussion and debate when presenting the tool and methodology to stakeholders. To pre-empt this in the focus group meetings a parking lot slide was presented, listing all issues relating to indicator time series and objectives previously mentioned. During this part of the presentation stakeholders were given the opportunity to clarify these issues and to add any new or missing information into this section, but with the emphasis that this would be taken up with stakeholders at a later date and not during the focus group meeting. As a result, and not surprisingly, this was an important point of discussion in each focus group. This theme displays the most distinct divergence in stakeholder focus across the different focus groups, with the EAF biologist and Sardine biologist focus groups spending more time discussing the data than the other two groups. The latter two groups consisted of experts previously consulted when identifying the ecological indicators used in the tool. Their level of knowledge of the indicators and dynamics of the sardine fishery and ecosystem would indicate a keen interest in the details of the data underlying the knowledge-based tool and how they are presented in the tool outputs.

In the EAF biologist focus group some time was spent discussing the validity of the objectives used to inform indicator selection, as well as a discussion on the difference between expert opinion and hard data. One stakeholder in this group insisted that a new objective and indicator be included in the knowledge-based tool. When asked why he felt this was an important indicator now, and not previously, he said that he had *“had some time to think about it now”*.

The Sardine fishery biologists were also interested in the indicators and, in contrast to the EAF biologists’ focus group, were interested in discussing trends in the tool outputs and relating these to their understanding of the system. Stakeholders in the Sardine biologists focus group voiced concern over indicators that fell below the bad threshold, suggesting that these may cause fishery managers losing trust in the scientific process. The Civil society and seabirds focus group only added one issue, the relative importance of anchovy and sardine in seabird diets, to the parking lot. The stakeholders in this group all work in seabird conservation and thus had a specific interest in this issue. The Fishery manager provided some insight into seabird data, as well as expressing interest in a tool that included anchovy (building a knowledge-based tool for the small pelagic fishery) as this reflects how the fishery is managed. The fishery manager was also interested in exploring the trends presented in the knowledge-based tool outputs, referencing his experience with fishing trends. Interestingly, the fishery manager focused on the detail and forgetting that the knowledge-based tool presents the overall implementation efficacy of EAF in the fishery. He is quoted as saying:

Fishery manager *"I tend to forget quicker that this is an EAF thing because I get into the data."*

The suite of issues identified for further investigation by stakeholders during discussions in the parking lot section of the meeting are summarised in Table 5.4.

Table 5.4: List of issues raised by stakeholders in the four focus groups. These issues were not addressed in the knowledge-based tooland were listed in the parking lot.

Focus groups	Topics to include in the parking lot
EAF biologists	Sardine recruitment Seabird diet Environmental influence on sardine and anchovy
Sardine biologists	Seabird diet Weight selection for seabird indicators
Civil society and seabirds	Seabird diet Anchovy indicators for small pelagic knowledge-based tool
Small pelagic fishery management	Seabird diet Separate seabird health east and west of Cape Agulhas (all species)

Theme 3: Audience

The stakeholders in all of the focus groups emphasised that the level of detail and how the tool outputs are visualised will depend on the intended audience for the tool.

Civil society/seabirds	*"The detail you present, it often depends on the forum you present it. A paper that you can sit and spend time on as opposed to doing a PowerPoint presentation to a certain type of stakeholder group."*
EAF biologists	*"...the managers may not be interested in everything and understand [the] flow chart you have... showing objectives first is better."*
Fishery manager	"*Whose shoes must I be in to look at this information? … Must I look at the tool as an advisor to industry or as a manager?"*
EAF biologists	*"The politician… when he sees this will want to know why, and how to rectify it [an indicator falling into bad threshold]."*

The intended audience for the knowledge-based tool varied depending on the focus group. Stakeholders in both the EAF biologist and Sardine biologist focus groups envisioned fishery managers as the primary audience for the knowledge-based tool. The Civil society and seabirds group felt that there could be a variety of primary audiences and emphasised that the knowledge-based tool should be tailored to each audience. That group viewed the focus group as an opportunity to reflect on how they would want to present the tool, if it were to be useful to them. The fishery manager felt the knowledge-based tool would be extremely useful for management, in particular to help make *"informed and defensible decisions*". This manager also felt they could not act on information presented in the knowledge-based tool without scientists providing recommendations on what management action, if any, should be taken to improve the performance of an indicator or objective.

5.3.2. Practical steps to improving communication

Stakeholders were asked for their input on practical changes that could be made to improve the communication and visualisation of the figures presented. The following results present the technical changes implemented as a result of these discussions.

5.3.2.1. Changes to presentation of the tool: Improving the bar chart

Given the choice between a vertical or horizontal bar chart in Figure 5.2 stakeholders preferred the tool outputs presented as a horizontal bar chart. When shown a more detailed version of the horizontal bar chart in Figure 5.3 the stakeholders reported that they found it difficult to read and interpret the figure, the text was too small and the objectives' hierarchy not differentiated enough for them to distinguish between the indicators and objectives. Stakeholders were then asked to suggest practical changes to improve this figure. These suggestions were considered and applied, within the caveat of continuing to use MS Excel to create the figures.

The resulting improved figure is presented in Figure 5.6. The objectives' hierarchy has now been distinguished through the use of solid lines below broad objectives and dashed lines below each specific objective. The horizontal axis labels have been separated by inserting lines between each label and grouping them to the related objective, which has been numbered to enhance readability. Bars for the objectives have been outlined in black to further distinguish them from indicator bars.

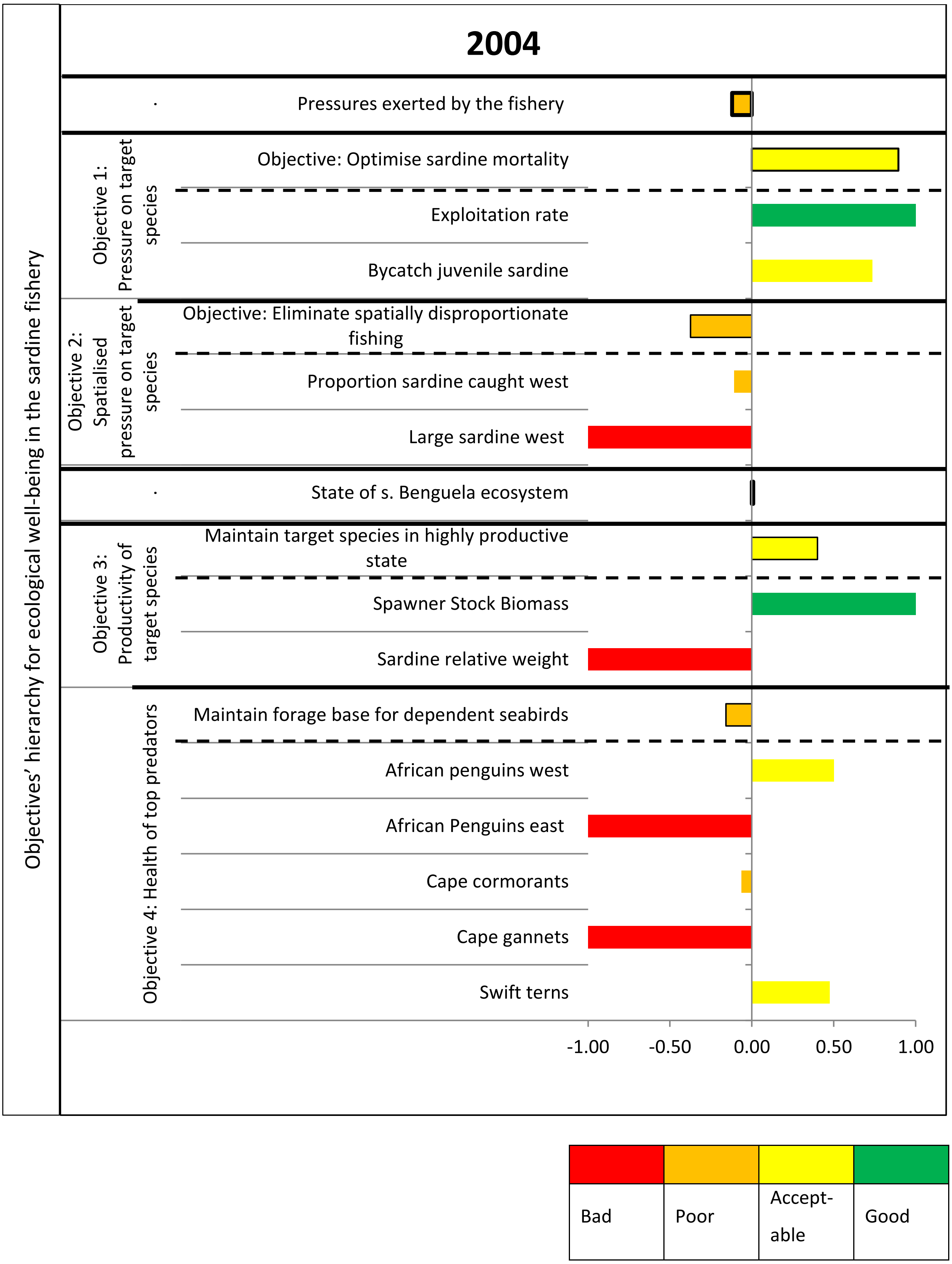


Figure 5.6: The revised presentation of the knowledge-based tool outputs. This improved figure incorporates the stakeholder's suggested changes to the presentation of the knowledge-based tool. The year 2004 was selected as a representative year in the time series applied in the tool development process.

5.3.2.2. Changes to presentation of the tool: Words and colours

The description of the knowledge-based tool in the presentation to the focus groups applied the same words and colour scheme as those used for threshold identification during expert consultations. Thresholds for each indicator were chosen based on a good, okay and bad threshold definition. Three colours, red, orange and green, were selected and assigned to ranges of output values. The bad values range from -1 to -0.5 and were coloured red; the okay values range from -0.49 to +0.49 and were coloured orange; and the good values range from +0.5 to +1 were coloured dark green (for example, Figures 5.2, 5.3 and 5.4).

The choice of colour scheme for the bars presented in Figure 5.3 was discussed in each focus group. To help with interpreting the figure, a bar showing a graduation of colour along the side of the figure was developed, the graduation of colours being linked to the output value range. For example,

EAF biologists *"It helps to read the interpretation [of the bar's colours] with the figure."*

Deciding if a set of five or six colours is better than a graduation of colours (from dark green, light green, light orange, dark orange, red, with white retained for outputs returning a value of zero) was discussed. Five colours were considered to be better than the three used previously, which followed a traffic light system: red, orange and green. The okay values should be presented in two shades of orange or orange and yellow to distinguish between positive and negative values. Careful consideration of the resolution of the selected colours to translate to a gray-scale of colours will help colour-blind users interpret the tool outputs.

Taking these suggestions into account, five colours were selected: red, orange, yellow and green, with zero being left unshaded in white (Table 5.5).

Table 5.5: The final suite of colours selected by stakeholders for describing the range of tool output values presented in the knowledge-based tool.

Red	Orange	White	Yellow	Green
-1 to -0.50	-0.49 to -0.10	-0.09 to +0.09	+0.10 to +0.49	+0.5 to +1
Bad	**Poor**	**Zero**	**Acceptable**	**Good**

Selecting words to relate to ranges of output values was more difficult. A suite of new words offered by the stakeholders as alternatives to the word 'okay' were put forward during discussion on word selection.

EAF biologists *"We still lack a language to deal with numbers."*

All four focus groups thought 'okay' and 'acceptable' seemed too positive for negative values. For example, two stakeholders commented that:

Sardine biologists *"Okay and acceptable are both positive words. Acceptable is more friendly than okay, should a positive word be used when indicator in the orange or negative value?"*

Civil society/seabirds *"I have a problem with the word 'acceptable', it sounds too positive."*

The words 'poor', 'worrying' and 'slightly bad' were offered to replace 'acceptable' for the range -0.49 to 0. 'Poor' was eventually chosen as an appropriate word to aid interpreting the outcome of an indicator or objective in a given year. The term 'acceptable' was retained for use to describe the output value range from +0.1 to +0.49. 'Bad' describes the range from -0.5 to -1 and 'good' any indicators or objectives that fall within the +0.5 to +1 range. The words 'bad' and 'good' were more widely accepted (the final word selection is given in Table 5.6).

Table 5.6: List of stakeholder selected words for describing the range of tool output values presented in the knowledge-based tool. The final selection used in presenting the knoweldge-based tool are given in the bottom row.

	-1 to -0.50	-0.49 to +0.09	+0.10 to +0.49	+0.5 to +1
Original words used in presentation	Bad	Okay		Good
New words suggested by stakeholders in the focus groups	Bad Poor Alarming	Acceptable Okay Poor Worrying Flagging Slightly bad, but not terrible All is not okay Neutral	Acceptable Okay Fair Encouraging Slightly good, but not great Neutral	Good Acceptable All is well
Modified words to use in tool outputs	**Bad**	**Poor**	**Acceptable**	**Good**

5.3.2.3. Temporal resolution and sequence of the presentation

Stakeholders at each focus group were asked if they preferred being presented with a figure with all the information summarised annually (i.e. Figure 5.3 and Figure 5.5) or with a trend over time for the broad objectives (option of a snapshot in time or a trend over time, for example, Figure 5.4) Across all four focus groups, stakeholders agreed that the figures showing the trend over time were most suited to the intended purpose of the knowledge-based tool and should be presented prior to the annual snapshot figures. The longer time perspective is important for strategic planning, and helps to provide context to changes or trends in indicators and objectives over time. Figures 5.7a and 5.7b show the revised order of presentation for knowledge-based tool.

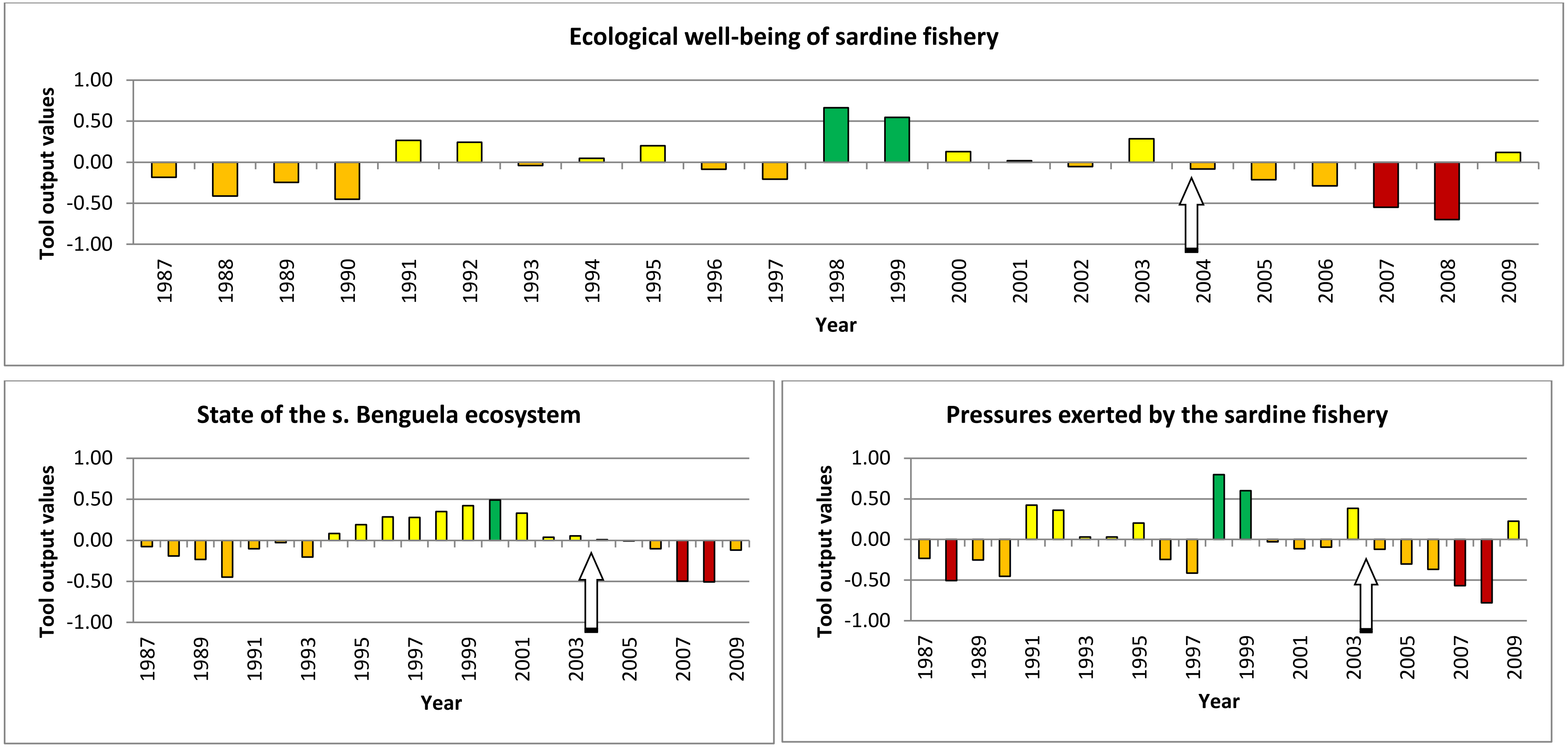


Figure 5.7a: The revised presentation of the knowledge-based tool outputs for the time period 1987-2009. Presented separately for the broad objectives of Pressure and State. The combined analysis of these objectives results in an assessment of ecological well-being in the South African sardine fishery, presented in the top panel. The arrow draws attention to the year 2004; this year has been selected as representative year in the knowledge-based tool time series (see Figure 5.7b). Stakeholders preferred the pyramid shape of this figure over the stacked presentation first shown to them (see Figure 5.4).

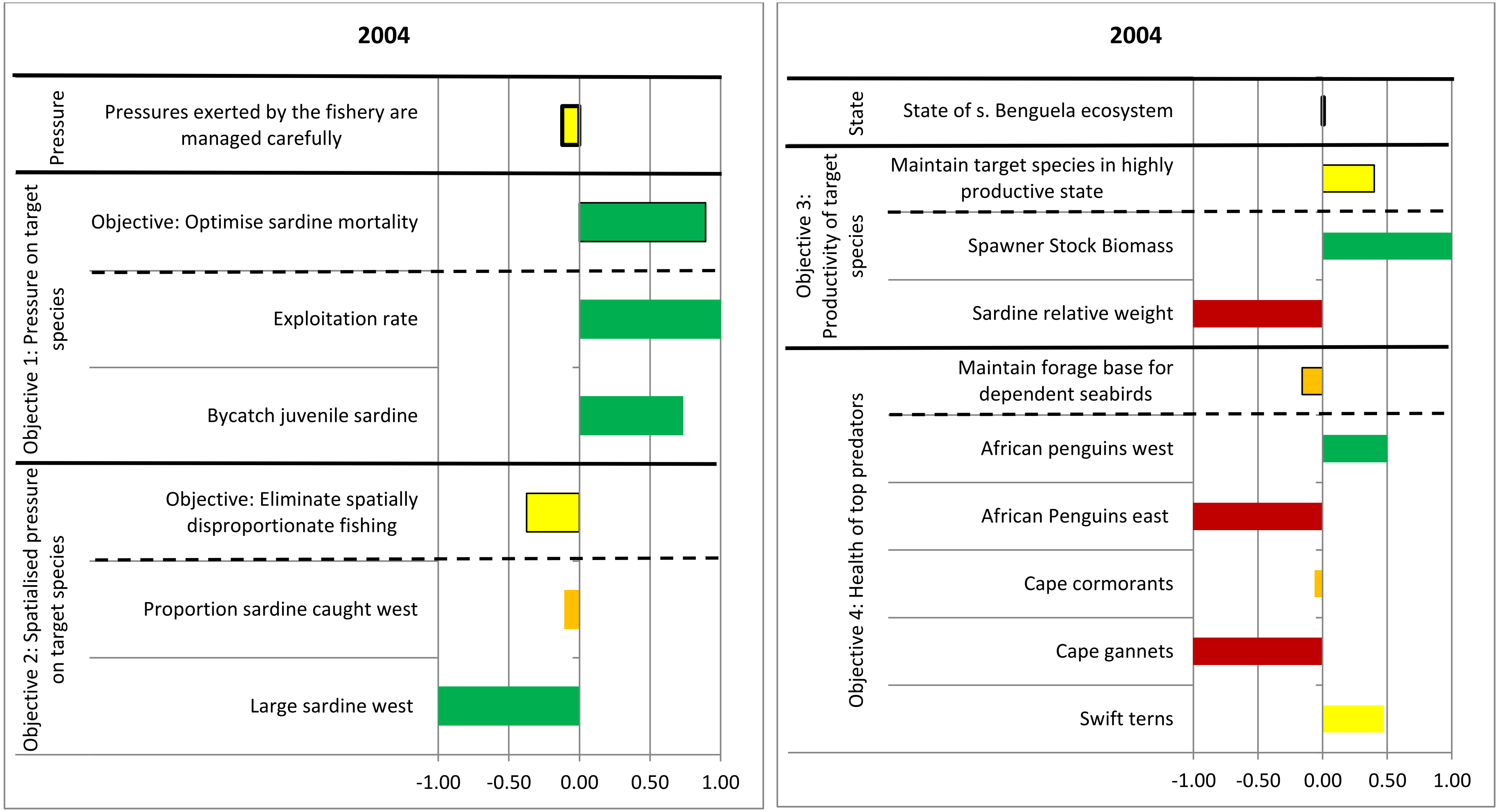


Figure 5.7b: The knowledge-based tool outputs presented as a snapshot of a single year for the broad objectives of Pressure and State. The year 2004 was selected as a representative year in the time series applied in the tool development process.

5.4. Discussion

5.4.1. Stakeholder participation

Exploring how to better communicate the outputs of the knowledge-based tool with stakeholders has allowed for further development of the knowledge-based tool. Grouping stakeholders into focus groups allowed further exploration of how stakeholders understood the outputs of the knowledge-based tool, which in turn helped to discussion around how the tool was developed and the possible applications of the tool with the stakeholders. The stakeholders identified to attend the focus group meetings were drawn from the EAF-SWG and SWG-PEL groups and DAFF management working groups. Those who attended the meetings represented key members from relevant organisations and reflected the breadth of participation in EAF implementation in the sardine fishery.

While not all stakeholders identified could attend a meeting, the meeting attendance was considered sufficient in all but the Small pelagic fishery management group. Senior members of conservation agencies were invited to participate, but due to busy schedules they did not attend. Nonetheless, the interests of the group were represented by other members of these agencies. Few junior members of the EAF biologist and Sardine biologist focus groups were able, or willing, to attend a meeting. It would have been good to have this group better represented and more work should be done to include these stakeholders in future iterations of the knowledge-based tool. Fishery managers were poorly represented and the difficulty experienced in finding a time and day that all managers could meet resulted in only one manager participating in this process. However, the managers approached all indicated an interest in the knowledge-based tool. Their busy schedules and more pressing issues reflect the perception that EAF in DAFF Fisheries management is of a less urgent nature. The relative priority of research and implementation for an EAF in DAFF is something I will address further in Chapter 6.

The stakeholders selected to participate in these meetings shared a similar interest, reflected in the names given to each focus group. Grouping stakeholders with shared interests together is considered appropriate practice for focus groups (Liamputtong, 2011). The intention of grouping similar stakeholders together was to reduce the conflicts that have developed in the SWGs (see for example the discussion in Hagen et al., 2014 and Chapter 6) and encourage creative and constructive comment on the knowledge-based tool. This was achieved in the focus groups; of course I could not discount the possibility that those who were more critical of the process did not prioritise attending a focus group meeting. The meeting structure helped to focus discussion and encouraged participation from each stakeholder in the meeting.

5.4.2. Meeting structure and key outcomes

The structured layout of the focus groups guided the discussion with stakeholders around the key questions relating to the communication of the knowledge-based tool and in particular around the style of presentation (graphic visualisation, words and colours for interpretation, detail to be presented) and ordering the tool outputs. A structured approach was needed to further the rapid prototyping component of the tool development process as stakeholder's time and availability to meet was limited. The meeting structure created the space for discussion around stakeholders' lines of enquiry and trains of thought as well as allowing discussions from points of interest raised during the meeting (for example, the parking lot). If the facilitator felt that a discussion or tangent followed wasn't constructive to meeting key questions in the allocated time for the meeting, the discussion was redirected or stopped.

Having such a structured approach to the meetings limited the depth of interaction among the stakeholders. This hindered to some extent the level of interaction I could allow in the meeting. However, as the questions asked of the groups were open ended and 'collective conversation' and interaction among stakeholders was encouraged this method was superior to one-on-one interviews or structured interview methods (Liamputton, 2011).

In anticipation of lengthy discussions on the underlying data and objectives used to build the knowledge-based tool, a subject widely discussed in previous meetings and not the goal of the focus group meetings, the parking lot was developed. As expected, a proportion of each focus group's time was spent on the parking lot. Stakeholders in the EAF biologist and Sardine biologist focus groups contributed to the development of ecological indicators that underlie the tool and the extent of time spent on parking lot issues in the meetings reflect their investment in tool development. The parking lot also enabled a change in stakeholders' individual understanding of the tool and the data that would help to reflect key elements of the ecological well-being of the sardine fishery. The importance of this discussion in the focus groups and during earlier meetings with stakeholders reflects the progress made in indicator development, monitoring and the availability of new data series since the identification of objectives in 2007.

Presenting the objectives as a time series in a bar chart was considered useful by all focus groups in providing context and facilitating interpretation of the output values in a single year. Displaying the knowledge-based tool outputs as a time series provides an important context for use in strategic planning for EAF implementation. This helped stakeholders to understand how the indicator values have changed over time, and they were also able to better identify the differences between the pressure and state objective and how these are combined to provide a value for the overarching ecological well-being objective. As a way of overcoming the concern raised over how well stakeholders without science-based training would take to the bar chart style of presentation, a table format was suggested as an alternative way to present the tool outputs. This approach was further developed after the focus groups and is presented in Table 5.3. Unfortunately, as no feedback sessions were held after the focus groups the response to the table could not be ascertained. The table certainly has some advantage over the bar charts as it is possible to view the outputs over time in a single figure for all the objectives; it removes the numerical presentation in favour of a traffic-light colour scheme denoting the efficacy of each objective.

All stakeholders involved in the focus groups have some tertiary-level training in the natural sciences, with the majority of the stakeholders actively involved in scientific research. As a result, it was not surprising that stakeholders in all of the focus groups agreed that the use of a bar chart to present the knowledge-based tool was acceptable. The presentation of data in this format is widely used in the natural sciences. In addition, this style of presentation has been used in similar methods for EAF implementation (Paterson et al., 2007, Nel et al., 2007, Jarre et al., 2008, Smith and Johnson, 2012). Many of the stakeholders have participated in one or more fora where this methodology has been developed and/or presented previously. As the aim of this research was to find a presentation style for the knowledge-based tool that is easily understood and communicated among stakeholders, the familiarity of this as a presentation style used in similar contexts before may have facilitated stakeholders' understanding of the information presented (Turnhout et al., 2007).

However, having the stakeholder group predominately based in natural science domain does not distract from the value of their input in this process. Many of the stakeholders who participated hold positions within their organization that require them to act in a management and communication role (for example, the CapeNature representative holds the position as an area conservation manager) or engage regularly with fisheries managers (for example, one stakeholder is chair of the SWG-PEL and is responsible for regularly compiling reports on scientific advice for management) and can thus contribute effectively to how managers may interpret the tool outputs.

Stakeholders have contributed practical changes that would make the tool more user-friendly to them and to the audience they thought would use the tool. Any new stakeholders included in future iterations of the knowledge-based tool must be involved in this component of developing the knowledge-based tool.

Interpreting the tool outputs can be improved by selecting colours and words that help to structure the understanding and clarity of the figure. The colours selected for the bars in the figures presented to the focus groups echoed the 'traffic light' colour scheme often used in work on ecological indicators (for example, Caddy, 1999, 2005, Koeller et al., 2000, Halliday et al., 2001, Ceriola et al., 2007, Jarre et al., 2008, Potts et al., 2008, Shannon et al., 2014). This choice of colour scheme works well with the thresholds defined in Chapter 4. The selection of an additional colour to differentiate the okay threshold into positive and negative values reflects the stakeholder's interpretation of the tool outputs and their concern for presenting the results as 'too positive'. This was an interesting reflection on the tool outputs.

The precautionary approach to managing sardine is considered in the fisheries management frameworks in South Africa (for example, Marine Living Resources Act No. 18 of 1998). Erring on the side of caution when faced with limited or uncertain data helps to safeguard against possible future failures or fishery collapse (Garcia, 1995). The knowledge-based tool provides a snapshot of selected indicators and objectives relating to the ecological well-being of the sardine fishery, and the stakeholders were aware of the limitations and caveats associated with the indicators, as they were, for the most part, the ones who contributed the data to develop them or have been part of previous discussions on indicator development. Cautious of interpreting the tool outputs as 'too positive' a picture of EAF implementation in the sardine fishery, stakeholders selected words that highlighted the need for improvement, i.e. selecting the words 'poor' and 'acceptable' rather than 'okay' for indicator and objective definitions in the tool. The choice of words to relate to numerical values will always be subjective; using thresholds agreed by experts and stakeholders minimises individual subjectivity and replaces it with group consensus. This keeps it in line with management's requirement of a scientifically defensible process.

The fishery manager expressed interest in being presented with solutions to improve the performance of indicators in the knowledge-based tool itself, as well as wanting to see the detail in the tool.

For example:

Fishery manager	*"What practical thing can I utilise to change the indicators?"*
	"[This tool] asks things of the manager to allow improvements in the objectives".

This is contrary to the EAF and Sardine biologist's assumptions that fishery managers would not want to have access to the details, but would rather focus on the broad objective outcomes. The Fishery manager's desire to see not only what is wrong and why, but also how to fix it was not anticipated. The knowledge-based tool as it is built in this iteration was presented as a strategic planning tool, highlighting where progress has been made towards implementing EAF for ecological well-being in the sardine fishery and indicating where more research or work should be directed to improve the situation. The knowledge-based tool can also help highlight where progress towards improving indicator status is already happening. For example, the tool can be used alongside research to contextualise the research in the EAF framework and to highlight any progress that has been made to fill research gaps identified.

5.4.3. Intended audience for the knowledge-based tool

Deciding upon the intended audience for the knowledge-based tool was an interesting point of discussion in the focus groups. This was not a topic covered in the key questions posed to the focus groups and instead came out of discussions among the stakeholders on the structure of tool outputs and the level of detail to present in the knowledge-based tool. The EAF biologist group envisioned the DAFF resource managers as the primary audience for this information. EAF in the sardine fishery has been mostly driven by members of that group, particularly in their roles as observers or members of the EAF-SWG (and/or the SWG-PEL). There is a perception among members of this focus group that EAF issues are not a high priority on the fishery management agenda. This has been demonstrated by the limited uptake of the scientific advice that has been generated by the group into management action. This is a legitimate concern of the EAF-SWG, and has been tabled on their meeting agenda a number of times (L. Hutchings, Oceans and

Coasts, Department of Environmental Affairs, pers. comm., C.D. van der Lingen, Branch Fisheries, DAFF, pers. comm.) The knowledge-based tool could act as a communication tool for managers, presenting the complexity and uncertainties of EAF in a transparent and scientifically defensible manner. The EAF biologists saw the tool as a possible bridge between science and management.

Stakeholders in the Sardine biologists' focus group also envisioned fishery managers as the primary user of the knowledge-based tool. During the meeting one stakeholder regularly referred to what the manager would want to see in the tool outputs. The fishery biologists are all members of the SWG-PEL which is the primary source of scientific advice for management. There is a clear pathway to management for advice generated by this group and a good working relationship between the SWG-PEL and the DAFF resource management working groups is a possible reason for the assumption that the knowledge-based tool would be most useful for managers.

The Fishery manager was supportive of the development of the knowledge-based tool and its application in the management system. They stated that the best use for the tool would be as a visual representation of the indicators, suggesting that the best place to use the knowledge-based tool would be on a wall in the DAFF offices, updated annually and visible for people to refer to at any time. But he stated that he cannot do anything, for example to implement spatial management of the fishery, "*until the scientists tell me to*", which points to the importance of the scientific advice generated and the role of the SWGs in producing sound information as a basis for management action.

The Civil society and seabirds focus group did not refer to managers as the audience for the knowledge-based tool. Stakeholders in this group focused on how they would like to see the outputs presented and how they interpreted the knowledge-based tools' outputs. These stakeholders shared their perspectives in management of their own organisations in relation to the key questions asked in the focus group meeting.

This suggests that this group, many of whom have links to management within their organisations, may see themselves as users of the tool.

It is worth exploring the use of the knowledge-based tool within organisations other than DAFF. A number of stakeholders external the government managing agencies play a leading role in research and implementation of aspects of EAF in the small pelagic fishery, including WWF South Africa, BirdLife South Africa and CapeNature, all of which were represented in the Civil society and seabirds focus group. These three organisations co-ordinate various EAF-related projects. Another overarching institution is the Responsible Fisheries Alliance, in which WWF South Africa, BirdLife South Africa and industry representatives participate. It would be worthwhile to explore closer collaboration with this institution in the future.

The EAF-SWG has supported the development and implementation of the knowledge-based tool, but the lack of implementation of the scientific advice they generate as well as limited time, human capacity and budget to do this work within DAFF requires this to be taken on by external groups, including the SARChI ME&F group, CapeNature, WWF South Africa and BirdLife South Africa. In this iteration the EAF-SWG was the primary audience for application of the knowledge-based tool. This group's position as leading EAF research and advice in government management is important and the knowledge-based tool can help to support decisions for monitoring and strategic planning around EAF implementation. However, alternative audiences for the tool should be considered. CapeNature, a managing agency responsible for seabird conservation and marine protected area management, could be an important user group for the knowledge-based tool, particularly for its application in strategic planning. Tailoring the tool for use in this group should be explored further in the next iteration.

5.5. Conclusion

This chapter completes the prototype knowledge-based tool developed through this thesis. Input from selected stakeholders during the focus group meetings has helped to improving the tool for effective communication by improving the visualisation of the tool outputs. The communication of model and expert system outputs is an important element of the process, but is often neglected in practice (Grey and Wiedemann, 1999, Chess et al., 2005). Spending time on this component of the knowledge-based tool development process with the stakeholders has improved stakeholder buy-in to the process and has helped to gain new insights into the tool development process, including identifying new audiences for the tool. Learning about new audiences for the tool, the organisations such as CapeNature and WWF who are working on approaches in support of EAF implementation in this process has helped to think about where EAF is being implemented and who influences strategic planning for implementation in South Africa. This is further considered in Chapters 6 and 7. It will be worthwhile to take these insights further when conducting new iterations of this process.

This chapter presents a leap towards creating a product that can be useful for its intended audiences. However, the social process involved in this mediated modeling exercise of building the knowledge based tool should not be overlooked. During the focus group meetings, the stakeholders had the opportunity to interact with one another and engage more deeply in developing the knowledge-based tool. During this I observed an improved understanding and buy-in of process the by the stakeholders. Having stakeholders with similar interests in the same group allowed a more creative and relaxed environment and enabled better stakeholder interaction and a deepening of understanding of the tool among the stakeholders than more mixed groups may have achieved. The success in this area if further explored in Chapter 6 which draws on social theories of social learning boundary crossing to explore the outcomes of the social processes around tool development.

Chapter 6

Towards implementing an EAF in the South African sardine fishery: Reflections on boundary crossing and social learning

6.1. Introduction

South Africa has committed to implementing an Ecosystem Approach to Fisheries (EAF). However, implementation has been slow, and effective implementation at an institutional level is yet to be achieved. Recent reviews in the BCC region (Cochrane et al., 2009, Staples, 2010, Augustyn et al., 2014) have identified a number of barriers, or boundaries, to successful EAF implementation at an institutional level. These include,

i. Fisheries departments largely "*structured on an outdated model that does not consider EAF*," resulting in EAF being driven by scientists rather than managers (Augustyn et al., 2014:12).

ii. No specific EAF management plans to outline operational objectives for the fisheries, or strategies on how to meet these objectives (Staples, 2010).

iii. The absence of an overarching structure in the relevant departments that can facilitate the integration of scientific information and balancing of management objectives for fisheries and conservation in line with an EAF (Staples, 2010, Augustyn et al., 2014).

iv. A lack of capacity at an institutional level to drive EAF, in particular a lack of dedicated EAF managers (Cochrane et al., 2009, Staples, 2010).

v. Difficulties in circulating relevant information, particularly social-ecological knowledge, through the fisheries management process (Augustyn et al., 2014).

South Africa leads progress in meeting EAF implementation goals in the region, but implementation is still far behind where it should be. The reasons for this can be attributed to the barriers mentioned above, and a lack of political interest (Augustyn et al., 2014), which results in implementation becoming extremely difficult to attain.

These barriers notwithstanding, the legal commitment remains and research in support of EAF implementation continues. Alternative routes to implementation are being successfully pursued and bridges across the boundaries to EAF implementation are actively being built, even if progress is still slower than required.

EAF-based research has a long history in South Africa. The research conducted in support of an EAF in the South African sardine fishery is highly regarded both locally and internationally (Shannon et al., 2004, 2010. Coetzee et al., 2008b, de Moor et al., 2011, Jarre et al., 2013, Augustyn et al., 2014). The former government Branch Fisheries Marine and Coastal Management had invested heavily in producing information on the natural sub-system (in 2010 this department was dissolved and the now DAFF and DEA were formed; see Chapter 2). Scientists at DAFF and DEA have continued to work to reconcile monitoring and research and produce the best available natural science information in support of both target resources-orientated Management (TROM) and EAF. This research is strongly focused on the ecological well-being component of EAF, building on the legacy of the BEP and BCLME programmes and other leading ecological and ecosystem-based research (see Moloney et al., 2004, Hampton and Sweijd, 2008, O'Toole, 2008 for overviews).

EAF-based research is conducted with notable support from academic institutions, with what is now UCT's MA-RE Institute taking a prominent role (Shannon et al., 2010), as well as from conversation agencies such as WWF South Africa, BirdLife South Africa and CapeNature through their involvement as members or observers on various DAFF/DEA SWGs and initiatives such as the Responsible Fisheries Programme.

Research for fisheries resource assessments is conducted within the Branch Fisheries Management of DAFF and supported through contracts to academic institutions, in particular the MARAM group at UCT (de Moor et al., 2011, de Moor and Butterworth, 2013). This information is addressed in the SWG-PEL. This research tends to follow TROM-based management approaches, where stock assessments are developed around managing the target resource and incorporate a limited number of objectives of fishery-ecosystem dynamics (Moor and Butterworth, 2011).

However, few EAF considerations are translated into fisheries management advice and much of the core EAF research, unlike the resource assessments, is conducted and funded externally to DAFF. The 2011 International Stock Assessment Review Panel (Smith et al., 2011b) noted that a gulf exists within small pelagic fishery management between the ecosystem modelling and resource assessment scientific research communities. The lack of cohesion between these groups has somewhat improved in recent years but still presents a barrier to progress in EAF implementation in this fishery.

A noted exception to this is the efforts to reconcile African penguin conservation and small pelagic fishery management. A Penguin Biodiversity Management Plan has been developed by CapeNature, a government conservation agency acting on behalf of DEA, and is the result of a stakeholder consultation process (DEA, 2013). This Plan presents a contrast to the usual distinctions between fisheries management and conservation by including research from DAFF, the fishing industry and academic researchers (for example, Weller et al., 2014, Ludynia et al., 2014).

In the small pelagic fishery, efforts to identify operational objectives and measures of EAF have been established outside of the managing agencies, with the MA-RE Institute, the UCT South African Research Chair in Marine Ecology and Fisheries group (SARChI ME&F), BirdLife South Africa and WWF South Africa leading this work. The Ecological Risk Assessment process (Nel et al., 2007, Paterson and

Petersen, 2010), the development of ecological indicators (Fairweather et al., 2006a, 2006b, Shannon et al., 2010) and the design of a knowledge-based tool for EAF implementation efficacy (Paterson et al., 2007, 2010, Astor, 2014 and this thesis) are key examples of external support for EAF in the small pelagic fishery. The DAFF and DEA staff actively participate in and support this research, but recognise that time and human resource constraints limit their ability to drive this work forward themselves.

A crucial challenge in EAF implementation is the translation of relevant scientific advice into existing management frameworks (Augustyn et al., 2014). The EAF-SWG was formed in 2007 to channel relevant ecosystem research into fisheries management through the then managing agency Marine and Coastal Management (EAF-SWG, 2007). After the dissolution of Marine and Coastal Management in 2010 the EAF-SWG has acted as a cross-departmental group, bringing together stakeholders from DAFF, DEA and other groups to address EAF concerns in fisheries management. The EAF-SWG maintained an open channel of communication between researchers at DAFF and DEA as well as other stakeholders, and was mandated with the co-ordination of research on EAF topics and to produce scientific guidelines for management. However, in contrast to other SWGs where scientific information is translated into advice for the relevant Resource Management Working Group and then sent through to the Minister for approval and implementation by management, there was no direct route for the information and advice generated in the EAF-SWG to be taken up by managers in DAFF or DEA (Hutchings, 2011, van der Lingen, YEAR). An EAF Steering Committee to address the scientific advice generated by the EAF-SWG at the resource management level was recommended by Staples (2010) but was not set in place. The lack of a clear procedural process for the EAF-SWG within the hierarchical structure of DAFF and DEA highlights a continuing boundary to the communication of EAF issues in government-led fisheries management.

Currently, the advice for management of the sardine fishery is generated by the SWG-PEL. *De facto* EAF considerations need to pass through this SWG to enter management advice. The SWG-PEL creates some space to include research on EAF issues in their agenda and official documents (de Moor and Coetzee, 2012, Moseley et al., 2012, Coetzee, 2013). Recently due to improved working relationships, a more open approach to EAF considerations and better communication among stakeholder groups has resulted in it becoming somewhat easier to place issues around EAF on the agenda in the SWG-PEL. In the past the working group meeting agendas were generally focused on resource assessment requirements and the development or revision of OMPs in consultation with stakeholders, primarily the fishing industry, leaving little space for discussion of ecosystem considerations.

To more effectively address EAF implementation in the South African small pelagic fishery the boundary between research and management needs to be bridged. Before attempting this, a more pressing boundary to effectively addressing EAF at the research level should be addressed. Two distinct and dissonant groups exist in the fisheries science community; those who focus on addressing fishery issues in the TROM approach and those who aim to implement an EAF. In light of the aim of this thesis to build a knowledge-based tool to assess EAF implementation efficacy, bridging the EAF/TROM boundary is important. As a result I focus on bridging the boundary between the TROM and EAF groups in this chapter. Boundary crossing offers the continuity needed to balance different perspectives and practices to allow for effective interaction in processes (Akkerman and Bakker, 2011a) such as that of meeting EAF implementation goals.

I hypothesise that the knowledge-based tool can act as a boundary object to facilitate boundary crossing across the EAF/TROM boundary. Boundary objects are artefacts, for example models (Cash et al., 2003) that are used to focus communication and interaction around a shared issue (Star and Griesemer, 1989). Boundary objects can support stakeholder interaction through structuring discussions between different perspectives or practices and translating information across boundaries (Star and Griesemer, 1989).

Institutions can support boundary crossing by offering important mediating functions across the boundary and by facilitating communication among stakeholders at the boundary (Wilson, 2009). I suggest that in EAF implementation in the South African small pelagic fishery, the university research group in which I am situated, the SARChI ME&F group can act as a boundary institution between EAF and TROM research.

Tracking the progress of knowledge-based tool development has required reflection on the role of the tool itself and more importantly, the process of participatory modelling around tool development. The nature of the knowledge-based tool's design required the application of principles of adaptive management and participatory modelling, which share the concept of learning-by-doing (Armitage et al., 2008, Berkes, 2009). This has resulted in the iterative evaluation and modification of the process with all the stakeholders (Berkes, 2009, Starfield and Jarre, 2011; see Chapters 3-5). Through this process, I hypothesise that by focusing on the building the knowledge-based tool the stakeholders involved have developed a shared understanding of the concepts around EAF implementation for ecological well-being in the sardine fishery, as well as creating a better understanding of the role of the tool development process in achieving this. Social learning can be used to make sense of the possible learning that has occurred through stakeholder interactions during tool development. Social learning is defined as the "*collective action and reflection that occurs among individuals and groups as they work to improve the management of human and environmental interrelations*" (Keen et al., 2005:4). Social learning is considered in this chapter as an emergent feature of stakeholder interactions, but I recognise that careful facilitation of learning processes may enhance social learning outcomes in these situations (Wals, 2007, Wals et al., 2009).

It is therefore the aim of this chapter is to draw on the theories of boundary crossing and social learning to reflect on the process taken in developing the knowledge-based tool for EAF implementation efficacy in the sardine fishery. I will then draw on these reflections to provide recommendations on how to proceed with the next tool iteration.

The initial aims of this thesis did not include exploring the social processes alongside tool development. This chapter is the result of retrospective reflections on the process by both me as researcher, and key process facilitator and with the input by my supervisors, linking our observations and experiences to the theories of boundary crossing and social learning. This chapter frames this thesis in the wider social processes that are considered important to ensuring the effective use of the knowledge-based tool for EAF implementation.

6.2. The knowledge-based tool as a boundary object

The knowledge-based tool provides a methodology to track EAF implementation efficacy in the sardine fishery and acts as a boundary object across the TROM/EAF boundary through synthesising the best available science from both sides into a more accessible format.

The methodology developed for designing the knowledge-based tool (detailed in Chapters 3-5) is strongly focused on maintaining stakeholder participation and engagement throughout the process. By building on existing collaborations with stakeholders developed through the ERA and ERA review processes (Nel et al., 2007) and first prototype expert system (Paterson et al., 2007, 2010) individuals from the EAF-SWG, SWG-PEL, UCT, Cape Nature, WWF South Africa, BirdLife South Africa, and representatives of the fishing industry were amenable to participating in tool development. When discussing the indicators for the knowledge-based tool in the EAF-SWG, it became clear that the group did not have sufficient expertise with respect to the indicators on stock size (a key indicator used in TROM). Through the co-operation with the SWG-PEL established during this research, representatives from both sides of the defined boundary now contribute to data collection and identification of indicators and thresholds that underlie the tool. The research questions addressed in Chapters 3 and 4 of this thesis were identified as important areas of investigation by the members of the EAF-SWG, with most of stakeholders in this group having participated in the knowledge-based tool process. Whilst new stakeholders were invited into the process, having the scope of this research mandated through the EAF-SWG has assisted in creating legitimacy for the process and buy-in for participation among the stakeholders. The recent dissolution of the EAF-SWG and has resulted in developing terms of reference for an EAF Task Team in the SWG-PEL (Coetzee, 2014). The internalisation of EAF in the PEL-SWG would offer a new opportunity to better integrate EAF and TROM issues in the current fishery management structures.

In meetings and focus groups held during the process of developing the tool, stakeholders worked together through careful facilitation to create joint input into the interpretation and communication of the outputs of the knowledge-based tool (demonstrated in Chapter 5). As a result, the knowledge-based tool has helped stakeholders from both sides of the boundary to integrate their knowledge and ideas for the tool, thus acting collectively in developing a new prototype. This was a new development and has improved the working relationship between the two groups. This is further demonstrated through the ease of access to data and willingness of stakeholder involvement in data collection process for a recent MSc. thesis on building a knowledge-based tool for the South African anchovy fishery (Astor, 2014). Astor met no boundaries to accessing meetings with key stakeholders and maintaining regular email correspondence with them while collating indicator time series and thresholds during her research. The familiarity of the process and tool development as a result of the research presented in this thesis on the knowledge-based tool for the sardine fishery has certainly facilitated this experience.

Keeping the focus on building the tool rather than having academic or technical discussions on EAF has helped to include stakeholders with different perspectives or limited technical knowledge on EAF. Thus, the methodology and way of thinking around the knowledge-based tool has been introduced to a wide audience. It has enhanced individual stakeholders' contributions by keeping focus on the well-defined tool rather than drowning out their participation by focusing on the overly technical points of the underlying indicators, or opening the discussion to general EAF philosophy. By splitting the stakeholder group into smaller focus groups, I was better able to support individual input and advance a shared understanding of the purpose, limitations and benefits of the knowledge-based tool among the group as a whole (see Chapter 5). Stakeholders were more receptive as a result of a deepened understanding of the process, stemming directly from these focus group meetings. Once again the support given to Astor's (2014) research demonstrates this.

It was important that the knowledge-based tool maintain its function and identity on both sides of the boundary. By developing a methodology for the tool that is scientifically defensible, repeatable and transparent, three essential characteristics for the tool to be useful for decision-making, the knowledge-based tool maintained independence and neutrality across the boundary. To effectively participate in the process, it was essential that individuals involved in developing the tool were content to use it as it exists. Focussing on developing a scientifically sound methodology made it easier to build trust in the process. This was reflected by the willingness of stakeholders to participate in meetings and share data for the tool. By agreeing to be part of the process, stakeholders entered into a space of mutual understanding; which provided the meeting ground for progress in boundary crossing through use of the knowledge-based tool.

6.3. A university research group as a boundary institution

The working relationships, buy-in and general research questions that this thesis is built on were already in place before this research began. The BCLME programme was highly successful in fostering working relationships between the various groups involved in EAF (Hampton and Sweijd, 2008, O'Toole, 2008). The EAF-SWG maintained regular interactions among stakeholders for EAF implementation within DAFF and DEA, inviting interested parties to sit on the working group and tabling key issues on their meeting agendas. The ERA and ERA review processes helped to create buy-in for EAF objectives among stakeholders involved in these workshops (Nel et al., 2007, Petersen and Paterson, 2010). Building on the BEP legacy, UCT MA-RE negotiated the space for research position at UCT (which is now the SARChI ME&F), with a strong impetus on research for EAF implementation, within the university and facilitated bringing in the leadership for this post from overseas.

The incentives for the reception of and participation in this research were the result of the sustained work undertaken by a group of researchers associated with the SARChI ME&F. Members of this research group have been working on bridging the TROM/EAF boundary by developing a number of approaches to support EAF in traditional management processes (Shannon et al., 2004, 2006, 2010, 2014, Fairweather et al., 2006a, 2006b, Watermeyer et al, 2008a, 2008b, in prep, Osman, 2010, Paterson and Petersen, 2010, Cury et al., 2011, Smith and Jarre, 2011, Smith et al., 2011a, Blamey et al., 2012, Ndjaula et al., 2013, Jarre et al., 2013, Hara et al., 2014, Ludynia et al., 2014, Weller et al., 2014, Jarre et al., under review).

Members of the SARChI ME&F group maintain formal and informal roles on both sides of the TROM/EAF boundary. Formal positions held by members of the group include: Prof. Astrid Jarre, the SARChI ME&F Chair-holder, full member of the EAF-SWG and formal observer on the SWG-PEL, and Dr Carl van der Lingen, former Chair of the EAF-SWG, head of the Pelagic Section at DAFF and an honorary research associate with the UCT MA-RE Institute. Maintaining these formal positions across the boundary ensured that there was accountability and transparency in their roles. These dual memberships have also played an important role in maintaining communication across the boundary and have, most importantly, created the space to support the use of the knowledge-based tool as a boundary object. Establishing the necessary interest to begin the knowledge-based tool development process would have been severely hampered without the formal recognition of core members' roles in both communities and the legitimacy this created across the boundary for the wider SARChI ME&F group. The less formal processes involved in informal boundary crossing by members of SARChI ME&F

group should not be overlooked; sharing office space, personal and professional working relationships and mentoring have all contributed to opening dialogue across the boundary. This in turn has created trust among stakeholders and the research group.

As a PhD student in the SARChI ME&F group I benefited from the collaborations that members developed and have been able to use them while developing the knowledge-based tool. As a result, opportunities to engage with stakeholders and the EAF-SWG were facilitated through these existing collaborations. At the same time, being a PhD student in this group allowed me to place myself in as much of a neutral role as possible, outside the TROM/EAF groups. The stakeholders involved accepted my role and trusted that I would act fairly in this process. As a result they were willing to engage in the development of the tool. Members of the TROM group were more willing to engage with the tool when it was seen as an academic, rather than a pragmatic, exercise (i.e. as a PhD project at UCT rather than a process of developing a model for the management process). Through external facilitation from the university or academic arena, seen perhaps as a more neutral and objective party, removed from fishery department agendas, and the willingness by stakeholders to support my research aims, this thesis research has contributed to softening the boundary and creating space for mediating information flows across the boundary.

6.4. Stakeholder interactions through tool development

The iterative process of knowledge-based tool development is shown in Figure 1.3 as a simple conceptual framework presenting the key steps taken to create the tool. Figure 6.1 expands on this framework, introducing the key steps in stakeholder engagement at each phase of tool development (text blocks). These represent opportunities for stakeholder interaction that may result in social learning.

Support for this research arose out of the SARChI ME&F group and has been further supported from the EAF-SWG. The core stakeholders in this round of knowledge-based tool development were present both during objective setting and formulation of the research questions. Being a part of the setting of the frame of reference helped in creating a shared understanding of the problem among the stakeholders. However, new stakeholders previously not involved in the process were invited to participate. As these stakeholders were not involved in the initial setting of the research scope it was assumed that they would trust that this process was representative of research needs and that it would be acceptable to them. The knowledge-based tool is supported through mandated research in the EAF-SWG and as a result most of the stakeholders had the incentive to participate in the tool development process. This has begun to bridge some of the concerns over trust of the relevance of this research in addressing EAF implementation among stakeholders, even if it has not yet completely resolved the trust concerns. Trust building is a central component of social learning (Cundill and Rodela, 2013), and should be included when developing the *process methodology* for the next iteration of the knowledge-based tool (see Chapter 7).

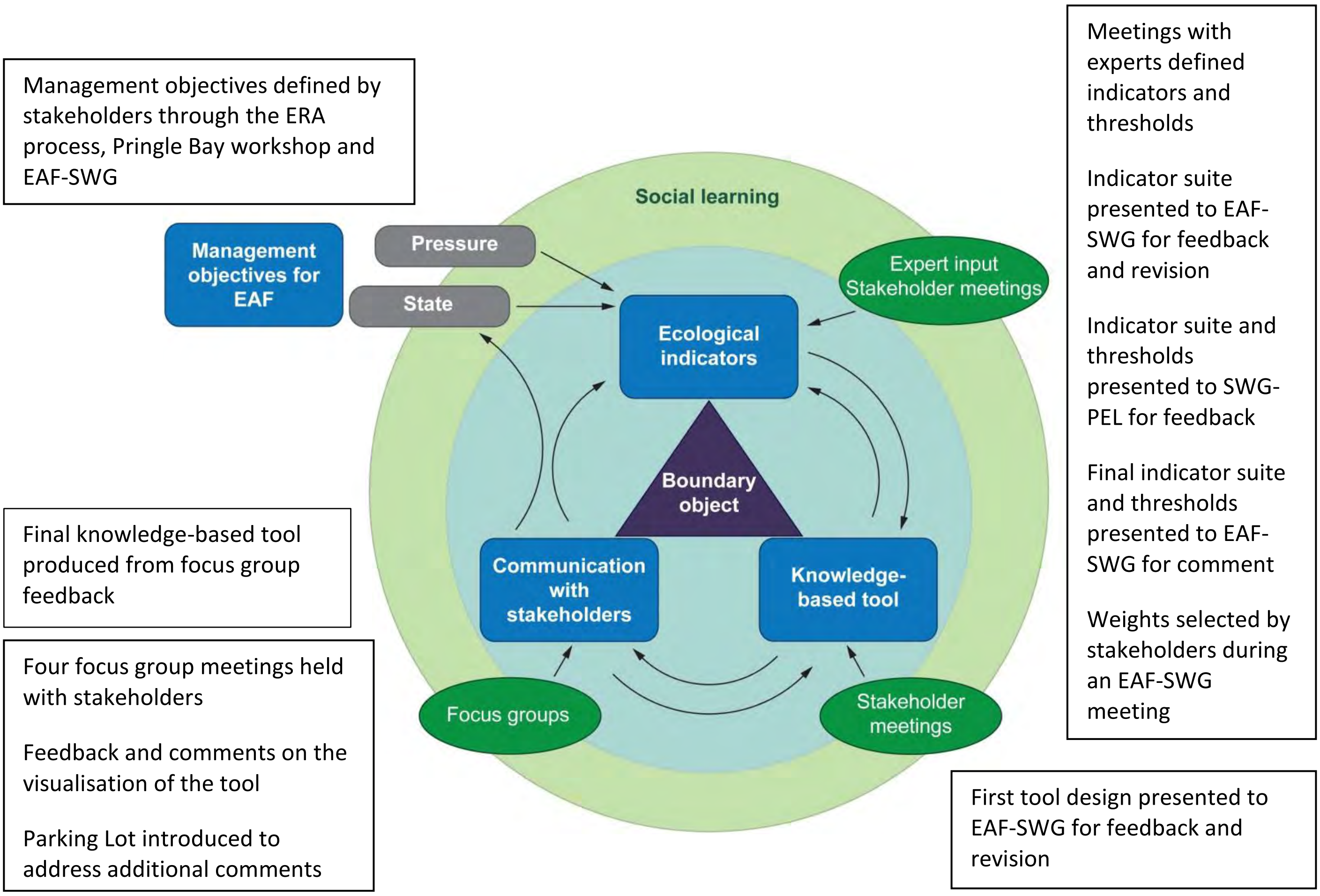


Figure 6.1: Key stakeholder interactions during the knowledge-based tool development process.

The SARChI ME&F research group has facilitated much of the early ground work in setting the research scope and incentives for participation in building the knowledge-based tool. Members of this group developed the early research projects in the first iteration of the knowledge-based tool (Jarre et al., 2006, Paterson et al., 2007, Jarre et al., 2008) and established a core group of stakeholders who later became important in supporting the development of this tool. These core stakeholders have an interest in ecosystem-based management and a view of synthesis and the bigger picture of EAF implications in fisheries management. Individually these stakeholders have provided a number of functions throughout the tool development process. From providing data, and advice for structuring the tool, to assisting in contacting stakeholders, organising and co-facilitating meetings as well as working in the periphery in keeping stakeholders involved in progress of knowledge-based tool development. Independent of particular institutional affiliation, the role of these core individuals in this process should not be overlooked as they are critical to maintaining interest and incentive for participation over the longer term (Shackleton, et al., 2009, Wals et al., 2009).

At the beginning of this project a series of meetings were held with key stakeholders at which the various steps required to build the tool were discussed (Figure 6.1). Each meeting began with a review of the research objectives and the purpose of the knowledge-based tool. Next, feedback of the progress made after previous meetings was presented, and it was clearly stated what the objectives of the present meeting would be. Ensuring stakeholders were of a similar understanding regarding the scope of the research and the intended input from them during the meeting assisted in focusing attention on building a common understanding of the task at hand. Regular feedback and space for comment and discussion in the early stages of the tool development helped reach a completed prototype in this iteration (see Chapter 5). However, for various reasons the time and scope of the research were restricted. This resulted in some of the content discussion around the objectives and indicators for EAF in the tool not being addressed during this process. These should be taken up in any future iterations of the tool.

The modelling philosophy applied in this thesis has followed Starfield and Jarre's (2011) rapid prototyping approach. My aim was not to perfect each step in the modelling process but to take the best available information at the time and build a simple model representing the stakeholders and my understanding of the system. Building the model this way, using stakeholder input, working on getting the best information possible, and conducting a thorough sensitivity analysis assisted in building a robust tool that stakeholders could interact with. Stakeholders were better able to understand where the data they provided fitted into the tool. The knowledge-based tool provided a common language and sense of purpose from which to engage in discussions around EAF implementation efficacy.

The group of stakeholders who contributed to the first stages of knowledge-based tool development represented interests from conservation, government, and academic institutions. This was essential in creating a shared understanding among all stakeholders. I found that during these initial meetings there was mention of assumptions that different stakeholders or groups of stakeholders, for example, those involved in management and conservation having very different perspectives on how to manage the fishery. These assumptions included considering that different audiences would have different requirements for the use of the knowledge-based tool or in how they would interpret the tool outputs. To test these assumptions and identify where similarities and differences in stakeholder views on the knowledge-based tool might arise, I chose to focus on communication and presentation of the knowledge-based tool (as the next step in the tool development process) and divide stakeholders into focus groups characterised by their professional interests, which included conservation and civil society, sardine biology, broader ecosystem ecology interests. This process was detailed in Chapter 5.

Importantly, the focus groups allowed stakeholders to reflect on the knowledge-based tool as it was being developed, and to clarify their needs and expectations of it so that the product of these meetings was a better shared understanding of the process. To this extent a shared group perspective has been developed.

The follow-up to this will be to return to the wider stakeholder group and build on this shared understanding. Ideally, more feedback meetings with a mixed group stakeholders would be held. This was not possible in this iteration of tool development. We also carefully considered the reason for splitting stakeholders into focus groups with people with similar areas or expertise or interest. The reason for this was to avoid some of the conflict between stakeholders that has been characteristic of the SWG-PEL in recent years. Hagen et al. (2014) document the nature of stakeholder interactions in the development of the African Penguin island closure project, one key task of the SWG-PEL. The nature of conflict had escalated as documented in Hagen et al., 2014 at the time of this research. So to get constructive and positive feedback during the research presented in this thesis mixed stakeholder groups were avoided during the later stages of tool development.

6.5. Creating balance: Rapid prototyping while not losing sight of the details

Prototyping the knowledge-based tool has created a product that the stakeholders can interact with rather than going through rounds of technical or academic discussions in the meetings without reaching consensus. The modelling process helped to focus attention on the purpose of the tool and quickly built an understanding of the complexity of the issue, which has been a good use of this approach. However if not done carefully, ‘parking’ the concerns of stakeholders could result in mistrust by the stakeholder(s) as they may feel like their input was being dismissed or considered unimportant. I observed signs of this during one of the focus group meetings where a stakeholder was concerned that his suggestion of a new, and to them a fundamental indicator, was not included in the tool. This stakeholder spent most of the meeting returning to that point, making it difficult for the group to keep focused on the task of the meeting. This demonstrates the importance of ensuring issues and concerns listed in the parking lot are taken up soon after the meeting. Addressing these in parallel to the modelling component will ensure that the stakeholders feel included and that their concerns are considered important, without slowing down the objective of prototype development.

Rapid prototyping can support improving stakeholders’ understanding of the system being modelled, potentially resulting in new ideas and sources of data being identified (Starfield and Jarre, 2011). Balancing the goals of building a full model prototype and making sure that stakeholders feel their input is valued and useful to the project is essential. However, maintaining this balance can be difficult. It takes time to address these side-concerns and distinguish between those which will improve the tool on the one hand and address issues brought up by individuals in the context of broader management of the sardine fishery on the other, which are either not being taken up elsewhere or are not compatible with ecological well-being objectives (see Chapter 3).

Without addressing side-concerns during the process, rapid prototyping might result in increased tension among individuals in the group and potential conflict later on. This may even result in loss of confidence in the whole process. Extra caution should be taken to address side-lined or 'parking lot' issues when rapid prototyping isn't as fast as it could be. For example, the period between two prototypes for EAF implementation in the sardine fishery (Paterson et al., 2007 and this thesis) was sufficiently long to experience a change in the composition of the stakeholder group. There was also progress in advancing scientific understanding of certain aspects of the system being modelled, for example the progress in understanding the effect of a spatial shift of sardine population and the resulting concerns around spatially disproportionate fishing (Coetzee et al., 2008b, Watermeyer, in prep). This meant that new stakeholders who were unfamiliar with the research were invited to participate in developing new prototypes, and new objectives and indicators needed to be considered in the tool.

Extra care should be taken to ensure all stakeholders understand the approach taken in rapid prototyping, and that it is not possible to include all issues or data in a model, developed under a rapid prototype approach (a model will always be a simplification of the real, complex world; Starfield and Jarre, 2011). Time should be allocated to exploring the side-issues placed in the 'parking lot' with relevant experts and stakeholders, bearing in mind time and budget constraints. This should ensure that the best available information is prepared and can be incorporated into the next prototype or justify and obtain agreement from experts and stakeholders on reasons to exclude particular issues in the next prototype. This would thus ensure that the stakeholders feel that their input has been considered and are comfortable with the modelling process and understand where (or when) information can or cannot be incorporated. The three elements which make the knowledge-based tool a useful tool for EAF implementation, namely repeatability, transparency and scientific credibility, are more likely to be maintained through the emphasis on process transparency and stakeholders may feel that their input and experience are valued.

6.6. Facilitating social learning at the boundary: Achievements, enabling conditions and next steps

On reflection, learning through the knowledge-based tool development process has supported progress in EAF implementation through refining ecological indicators and thresholds and has influenced a change in stakeholders' understanding of EAF in the sardine fishery. Through this process, the majority of the stakeholders have become more receptive to working together. Signs of this have been observed in the willingness of stakeholders to attend meetings, joint publication of research and the support of Astor's (2014) Masters dissertation. By focusing on the process as whole rather than entertaining purely technical discussions on a specific indicator or the EAF concept in an abstract way, stakeholders have become more aware of where their individual inputs can fit into the EAF context, and feel that their contributions were valued in the process.

Stakeholders have had the opportunity to learn both from one another and together as a group, or as small groups in the case of the focus groups through the development the knowledge-based tool. By working together on building the tool, stakeholders have had the opportunity to learn more about the trade-offs, priorities and complexity of EAF in the sardine fishery. The knowledge-based tool requires that stakeholders to provide input into structuring the objectives' hierarchy and building the tool, including selecting weights for objectives and indicators within the tool which helps to give perspective to the uncertainties, data requirements and understanding of the system. In addition to the progress in scientific understanding, working on the tool provided a methodology and transparent process which guided stakeholder interactions. This can help to bridge some of the boundaries between different disciplines and helps to contextualise research and stakeholder expertise in building a shared representation of the issue.

This progress suggests that social learning has emerged during this process. The extent to which this progress has been observed in the process of knowledge-based tool development for EAF implementation has resulted from the interaction among stakeholders around the shared task of developing the knowledge-based tool. With social learning the result of such interactions (Wals et al., 2009), the barriers to successful EAF implementation in the management of the sardine fishery can be bridged by effectively engaging stakeholders in a social learning process. Observing social learning as an emergent phenomenon among a group of stakeholders who are both heterogeneous (representing different interest groups) and homogenous (in that they are all trained in the natural sciences) provides a proof of concept for future work. It is through this difference and possible points of tension or conflict that the greatest opportunity for learning occurs (Wals et al., 2009). Working across the EAF/TROM boundary the knowledge-based tool acts a boundary object in facilitating stakeholder interactions. As a result, the knowledge-based tool functions both as model for structuring EAF objectives and indicators, but also as a tool for boundary crossing and facilitating stakeholder interactions at the EAF/TROM boundary.

A facilitated social learning process undertaken within the next round of tool development will improve the social interactions within the knowledge-based tool development process and can be particularly useful when expanding the knowledge-based tool to include objectives for the ability-to-achieve dimension and improve the human well-being dimension of EAF. This will need continued focus on building the knowledge-based tool to account for changes in the management objectives and indicators. This process will benefit from including stock assessors and various industry representatives as new stakeholder groups.

Having a group of researchers committed to this approach and to EAF implementation in the sardine fishery has been invaluable to creating an enabling environment for this research. Many of the stakeholder relationships have been nurtured through long standing working relationships with key individuals in this process. The SARChI ME&F group has driven this work and has helped to create the space for conversations on this approach to take place with the managing agency through roles of individuals in this group within the SWGs. Their interaction and support in capacity building and maintaining relationships prior and during this research cannot be overlooked and are important to support future social learning processes (Shackleton et al., 2009, Wals et al., 2009). Part of this success has been attributed to the long term, flexible funding provided through the SARChI ME&F group. Having flexible and secure funding is essential for supporting social learning processes (Shackleton et al., 2009).

Seeking opportunities to advance EAF implementation in the small pelagic fishery relies to some extent on the willingness of stakeholders to engage with the issues and the enabling conditions in which to do so. Founding the EAF-SWG was an important development as was the annual International Stock Assessment Review panel's recommendations to include more EAF considerations in the TROM-driven stock assessments (Smith et al., 2011b). Additionally, the increasing number of ecological consideration included in the SWG-PEL meeting agendas offer opportunity to include EAF in fisheries management advice. These spaces were negotiated by individuals or groups with a strong interest in EAF implementation. These brokers (Akkerman and Bakker, 2011a) acted across existing boundaries to facilitate progress in EAF implementation. The progress of changing the way things are done to advance EAF in fisheries management has occurred gradually through boundary work of individuals and groups such as the SARChI ME&F, WWF South Africa, and BirdLife South Africa. There are critical moments when there is opportunity to address an issue or gap in management through an intervention, such as establishing the EAF-SWG, which makes a big leap in progress. It is these interventions that Sol and Wals (2014) refer to as tipping points. These authors draw on Sheffer's (2010) concept of tipping points in complex systems to explore transformative processes occurring during the development of hybrid learning environments in kindergardens in The Netherlands (Sol and Wals, 2014). A tipping point is conceptualised as a "*means of identifying critical events in the transformation process*" (Sol and Wals, 2014).

The concept of tipping points in transformative learning processes (Sol and Wals, 2014) offers some interesting insights into understanding progress, or lack thereof, in EAF implementation in the small pelagic fishery. Anticipating critical moments during phases of a learning process can help in addressing boundary issues, for example, the phases in developing the knowledge-based tool could be further unpacked to observe moments when this intervention could impact process changes. Further exploration of the concept of tipping points in the development and uptake of the knowledge-based tool in the management of the small pelagic fishery should be considered in future research. The formation of the RFA in 2008 could be considered a tipping point. This group aims to address EAF implementation through various channels including training skippers and supporting research to find ways to balance the resource-extraction-related and conservation-related objectives, progressing EAF implementation alongside the government efforts. The recent dissolution of the EAF-SWG and possible development of EAF Task Teams within the SWG-PEL in early 2015 may be another important tipping point in EAF implementation in South Africa. Being prepared and having facilitators who are able to identify tipping points and act accordingly to introduce effective interventions at the right time will be necessary (Sol and Wals, 2014).

Acting on the issues placed in the parking lot during this round of knowledge-based tool development will be the first step towards a concerted effort to facilitate social learning in this process, as this will address the concerns stakeholders have expressed, and ensure all are on the same page in the approach taken. Addressing the issues set aside during knowledge-based tool development will require some time spent with the individuals who identified the issues. Understanding why these were considered important will help in gaining a perspective into the worldview held by the respective stakeholder(s) involved in the process. Addressing stakeholder concerns in the parking lot will help to improve trust in the process and improve understanding of the strengths and limitations of both the tool and the development process, and therefore ultimately improve the knowledge-based tool. Following Wals et al. (2009), being aware of different worldviews and perspectives held by stakeholders and careful consideration of points of conflict or tension, as well as creating a space to present and value different worldviews will play an important role in enhancing both EAF and the knowledge-based tool among the wider group of stakeholders.

Reviews of EAF implementation in South Africa suggest that one of the key barriers to effective EAF implementation at an institutional level is that EAF is still predominately being driven by science and for the most part ignored in management (Cochrane et al, 2009, Staples, 2010, Augustyn et al., 2014). The objectives and ways of operating are different in science and management (Wilson, 2009). Driving EAF from a purely scientific point of view may hinder the progress made in implementation. Science requires a more cautious approach, often wanting the data to be accurate, making explicit any uncertainties and if following academic science, making sure that the information published is as good as it can be. In contrast, management works on a much tighter time frame and requires the best available information at a given point of time (FAO, 2003). EAF increases the uncertainty around proposed management strategies (Garcia and Cochrane, 2005), and increased uncertainty may make data seem less reliable. Often decisions need to be taken with inconsistent data or shorter observation periods than what is required in science-based data for TROM (Butterworth and Plaganyi, 2004). Recently, progress, albeit somewhat limited, has been made in including ecosystem-based management advice into TROM stock assessments (de Moor and Coetzee, 2012, Moseley et al., 2012, Coetzee 2013). This is demonstrated by the inclusion of considerations African penguin health in OMP-13 (Robinson, 2013), the consideration of a two stock hypothesis in the OMP-13 (de Moor et al., 2014) and the examination of long-term environmental changes on fish species (Jarre et al., 2013, de Moor and Butterworth, year WG DOCS). The support to consider African penguin dynamics and two-stock hypotheses in the OMPs came from local discussions originally (Nel et al., 2007), and was reinforced by recommendations from the annual International Stock Assessment Review panel (Smith et al., 2011b, 2012, 2013) as well as advancements in fisheries management advice produced in Europe and elsewhere (Hofmann et al., 2010, Jennings et al., 2014, Link and Browman, 2014). To further include EAF considerations in management advice, we need to ensure that all stakeholders are aware that using best available information and rapid prototyping approaches to modelling are better than waiting until the most accurate information is produced.

International pressure to engage more effectively across the EAF/TROM boundary to co-produce science for management has driven some interaction and participation. However, this has not addressed some of the more on-ground issues around EAF/TROM interactions. Social learning offers a potential method to address boundary crossing in this context, allowing for effective and transformative learning through interactions across these differing perspectives. Stakeholders are encouraged to work together to create trust and build social cohesion, learning from one another and together to improve understanding of EAF implementation efficacy. The use of the knowledge-based tool as a boundary object helps to guide this process, and as demonstrated here has been successful in establishing the value of focusing stakeholder attention around a shared problem. Cash et al. (2003) found that models acted as effective boundary objects, creating a transparent and legitimate process for stakeholders to access information and bridge science-policy gap in acid rainwater management in Europe. Mackinson and Wilson's (2014) recent paper suggests boundary objects created through participatory action research can help bridge science-policy gaps in EU fisheries management and help better understand complex issues, such as an EAF.

The research conducted in this thesis is situated predominately on the EAF side of the TROM/EAF boundary. This is expected as the key aim of this research was to focus on EAF implementation efficacy and has been funded accordingly. Stakeholders on the TROM side of the boundary were included in this process and have participated in indicator identification and tool development. Some of the data that are defined in the stock assessments have been included in the knowledge-based tool (for example, de Moor et al., 2014). This helps, if not to fully bridge the boundary, to certainly begin to blurring the edges. Success in this regard has been due to individual stakeholders who are willing to participate and are more open to conversations around EAF and TROM compatibility than others.

This chapter has relied on a reflective perspective observing emergent social learning processes through tool development. It was not the initial intention of this research to address deeper social processes that result from getting people in the same room and engaging them in discussion through the structured approach applied in developing the knowledge-based tool. With the focus on process iterations in this research I have been able to reflect on the progress and the challenges in implementing both the tool developed in this thesis and the broader EAF context in which this process has been situated. The hard results of this research are well documented, and include ecological indicators, thresholds and the knowledge-based tool itself. The softer process outcomes which form the means to reach these harder results, for example, improved personal relationships, collaboration, social cohesion, conflict resolution, were not directly evaluated during the process. Monitoring and evaluation of process criterial for social learning provides a means to more effectively enhance social learning outcomes through encouraging active reflection and feedback by stakeholders involved in the process. Cundill (2010) explored developing a methodology for monitoring of social learning in adaptive co-management processes in three case studies in South Africa. Cundill's approach included developing a suite of key variables and outcome indicators for collaborative monitoring. These were tailored to the case studies but may provide a starting point for considering process outcomes in similar participatory learning contexts.

Indicators are useful in providing a qualitative measure towards meeting anticipated goals or process outcomes. They are particularly useful in management contexts where hard results and visible outcomes of processes are needed for transparent decision-making (Belton and Stewart, 2002). However, having predetermined results and the process outcomes by experts or managers precludes the possibility for social learning by removing opportunity for shared perspective building and development of innovative change solutions (Wals et al., 2009). Collaboratively agreeing on a set of key variables and outcome indicators of the soft processes with stakeholders and regularly evaluating and monitoring the process will help to balance the need to track progress for process accountability while building in more reflexive practices and learning processes into the project. More emphasis on evaluation and monitoring of both the hard and soft process outcomes during the knowledge-based tool development process should be considered in any new iteration.

6.7. Conclusion

Implementing an EAF requires a paradigm shift, moving away from single discipline focused research towards trans-disciplinary co-operative management of fisheries (Berkes, 2012). Encouraging stakeholder participation and maintaining working relationships will be invaluable to the success of future work on knowledge-based tool development for EAF implementation. In addition, creating fora for fisheries researchers to interact and build social and professional relationships will help to overcome the boundaries that currently exist.

As a result of these findings and the enabling conditions within this research, I suggest that a carefully facilitated social learning process should be built into the next iteration of the knowledge-based tool. Social learning will enhance the outcomes of the tool development process and support bridging boundaries to EAF implementation in the sardine fishery. The use of the knowledge-based tool as a boundary object to facilitate social learning should be expanded on in new tool iterations. Recommendations on how to do this and a suggested framework on how to facilitate social learning in the knowledge-based tool development process will be detailed in Chapter 7.

Chapter 7

Synthesis and conclusion

7.1. Thesis overview

Implementing an Ecosystem Approach to Fisheries management, while internationally recognised as being important to achieve sustainable fisheries, has had limited success. This thesis has focused on developing a tool to evaluate the effectiveness of EAF implementation in the South African sardine fishery. The knowledge-based tool developed as central to this thesis introduces a transparent, repeatable, and scientifically defensible methodology for evaluating indicators against objectives for the ecological well-being dimension of EAF in the sardine-directed fishery. The knowledge-based tool provides an effective synthesis of objectives for ecological well-being that can be useful in understanding trade-offs and priorities for EAF implementation in the sardine fishery and communicating this among stakeholders.

Jarre et al. (2006) and Paterson et al. (2007) set the foundation for this research by developing the concept and a 'proof of concept' expert system for EAF implementation efficacy in the South African sardine fishery, respectively. This thesis has drawn on that early prototype and extended the application of the knowledge-based tool to include broader consultation and participation by stakeholders (Chapters 3-5), a refined suite of ecological indicators (Chapter 3), alternative synthesis methods (Chapter 4), and placed more focus on communicating the tool among stakeholders (Chapter 5). Paterson et al. (2007) focused on process development over ensuring a scientifically valid and robust tool. I have taken this early prototype further in both the product, the knowledge-based tool (Chapters 3-5), and the social process around tool development (Chapters 5 and 6).

Progress in building the knowledge-based tool has been conceptualised in this thesis as a cyclical process based on a series of iterations (Figures 1.3 and 6.1). Following

Starfield and Jarre's (2011) rapid prototyping approach, I aimed to design the simplest tool possible using the best available information. Applying this modelling philosophy helped me to make progress despite missing or poor quality data, and helped to circumvent circular arguments among stakeholders on the finer details of the data. By drawing on the best available scientific information and consulting with experts during indicator and tool development, the knowledge-based tool meets the requirements of fishery scientists and managers who need to base their decision-making on defensible scientific information.

Eleven ecological indicators linked to nine management objectives for the ecological well-being of the sardine fishery were developed in Chapter 3. The indicators were based on the best available scientific information and expert knowledge at the time, and the stakeholders consulted agreed that they represent the most appropriate measure of the management objective. These indicators provide the base on which to build the knowledge-based tool. Chapter 4 outlined the tool development process, detailing thresholds defined by experts for each indicator, the aggregation method decided on by stakeholders, and the selection of weights in the tool. Each step in building the knowledge-based tool relied on stakeholder input and feedback. A thorough sensitivity analysis showed the tool to be robust to changes in indicator thresholds and weight selection. Stakeholder engagement ensured that this iteration of the knowledge-based tool was appropriate and acceptable to those involved in building the tool as well as potential users of the tool, in this context the members of the EAF-SWG who were actively involved in, and encouraging of, building the knowledge-based tool.

Effectively communicating the outputs of the knowledge-based tool among stakeholders is important for the shared understanding and the application of the tool in strategic planning for EAF in the sardine fishery. Recognising this, Chapter 5 further explored how to communicate the tool outputs. Through a series of focus group meetings with groups of stakeholders I refined the visual presentation of the tool. Beyond the practical revisions to how I presented the knowledge-based tool, the stakeholders had useful insights into the application of the tool, and the intended audiences, and raised important concerns they had over particular indicators or information they considered missing from this iteration of the tool. The parking lot used during the focus group meetings helped to give a space for stakeholders to air their concerns and document them so they can be addressed in side-line conversations and in the next iteration of the knowledge-based tool.

Fostering participation in objective setting and decision-making among diverse groups of stakeholders is required to support an EAF. I aimed to maintain stakeholder engagement at each step in the development of the knowledge-based tool. However, it is not enough to get people in the same room. Effective communication and social cohesion among all stakeholders and across boundaries to EAF implementation are required to make progress. In the reflections on building the knowledge-based tool in Chapter 6, I hypothesised that the knowledge-based tool and the university research group (SARChI ME&F) in which it has been developed maintain important functions in boundary crossing between the differing research perspectives of the EAF and TROM research groups. By acting as a boundary object the knowledge-based tool can help to support communication and to develop shared perspectives across this boundary. Individuals within the SARChI ME&F group have had and will continue to have an important role to play in supporting the knowledge-based tool in this function.

I adopted an applied research approach in setting the scope of research for this thesis and the research aims were expanded throughout the development of the knowledge-based tool as the outcomes dictated. As much as I was the principle researcher in this project, I was also an active participant both through process facilitation and in building the tool. I brought my own biases and interpretations to the process and I cannot untangle how my understanding of the system dynamics in the sardine fishery and social processes occurring during tool development may have influenced the outcomes of this research.

EAF implementation will require new and innovative solutions and ways-of-doing-things, requiring diverse groups of stakeholders to come together and interact in positive ways. Social learning has been described in Chapters 1 and 6 as offering an opportunity to take advantage of differences in perceptions, practices, and interests among stakeholders by fostering stakeholder interactions. While not an explicit aim during tool development, characteristics of social learning were observed during this process. Reflections on these emergent features of social learning through tool development can be enhanced by more careful facilitation of social learning in future iterations of the tool.

The interdisciplinary nature of this research helps to advance a holistic approach in assessing EAF implementation in the South African sardine fishery. Balancing attention on achieving a robust and scientifically defensible tool and ensuring stakeholder interaction through encouraging positive social interactions around tool development has been achieved in this iteration of the knowledge-based tool. This tool contributes a new method in the growing toolkit of methodologies in support of EAF implementation in South Africa and has contributed to improving the process of implementing an EAF in the sardine fishery.

7.2. The effectiveness of EAF implementation in the South African sardine fishery

South Africa has a strong science base for EAF, particularly for the ecological well-being dimension; however, due to capacity constraints DAFF has been slow in implementing this approach. EAF implementation for the ecological well-being of the South African sardine fishery has been limited, despite being a tractable fishery for EAF implementation in South Africa. The implementation efficacy of EAF as measured in the knowledge-based tool has been relatively ineffective (see below) over the period investigated in this thesis.

Only three of the 22 years observed in the knowledge-based tool stand out as good years for the ecological well-being of the South African sardine fishery: 1992, 1998 and 1999. In these years the pressures exerted by the sardine fishery were carefully managed, little or no spatially disproportionate fishing occurred, exploitation rates were low, and sardine recruitment in the year prior to these years was high. The state of the southern Benguela ecosystem was moderately affected by the fishery, returning 'acceptable' output values in these years, and was predominately driven by seabird abundance and sardine spawner stock biomass reaching acceptable levels in those years.

Understanding the drivers of good years in the knowledge-based tool can highlight favourable conditions for the ecological well-being of the sardine fishery. Years when pressure indicators return good values may illustrate effective management of the fishery, as the pressure objectives can be linked to changes in fisheries practices. In addition to understanding the impacts of fishing pressure during years presenting good states, indicators may also demonstrate favourable environmental conditions. These findings can be applied when prioritising research and management objectives and strategic planning for EAF within DAFF and other institutions supporting EAF implementation.

The pressures exerted by the sardine-directed fishery show sharp differences over the time period observed by the knowledge-based tool. The rapid change in the evaluation of this objective has been the result of both the dynamic nature of the sardine population and response by fishery management to changes in stock biomass and recruitment success. Key drivers of this objective have been the impact of spatially disproportionate fishing on the sardine population. Two new indicators were specifically developed in this thesis to address this objective in the knowledge-based tool. Objectives and indicators may need to be revised following recent progress in understanding the impacts of the shift in the sardine population from the west to south coasts and the possibility of multiple sardine stocks.

State objectives may be influenced both by fishing and management interventions but also by wider ecosystem changes such as environmental drivers or human disturbance. In the knowledge-based tool, the state of the southern Benguela ecosystem was shown to be negatively affected by fishing activities over the time period investigated. This objective is strongly driven by the condition of seabirds that are heavily dependent on sardine in their diet. The well-being of African penguins in particular featured heavily in the weighting of the indicators and is a contested point in EAF discussions in South Africa. The African penguin populations are listed as Endangered on the IUCN red list after drastic declines in population size. This decline is considered as a result of fishing impacts and other drivers, notably oiling and predation at sea. There have been significant advances in understanding of fishery-seabird dynamics and this has contributed to improved indicators for seabird abundance over the last few years, in particular African penguin well-being in relation to available prey species. These advances have the potential to support more effective EAF implementation through improving the scientific knowledge base.

The sensitivity analysis conducted in Chapter 4 showed the knowledge-based tool to be robust to changes in how the objectives and indicators were weighted as well as to changes in indicator thresholds. This was an important exercise and demonstrates the strength of the tool and supports the claim of a scientifically defensible tool for use in the management context. Interestingly, the years highlighted as sensitive to changes in weight - 1994, 2001 and 2004, have been identified by Blamey et al. (2012) as important years during regime shift periods in the southern Benguela. It will be worth further investigating these periods of environmental change when developing indicators for the governance dimension of EAF (which includes more climate or environmental change elements).

The knowledge-based tool incorporates stakeholder priorities through weight selection, and stakeholders chose to weight the pressure indicators higher than state indicators in this iteration of the tool. Pressures can be better controlled through management interventions, and therefore provide a more accurate indication of the progress made to implement an EAF in the sardine fishery. While the state of the ecosystem is important to monitor, stakeholders assigned these objectives a lower weight in the objectives' hierarchy because environmental drivers such as climate variability will influence these indicators and cannot be directly influenced by fisheries management. These are not directly included in the knowledge-based tool, which does not yet have an ability-to-achieve dimension. Changes in the composition of the stakeholder groups, new data or revisions to objectives may change the way objectives and indicators are weighted in the tool. Weight selection in new tool iterations will need to be revisited as the knowledge base underpinning indicators improves.

7.3. EAF implementation in South Africa

While implementation may be slow on the ground, a concerted effort to implement EAF concepts and principles in South Africa's fisheries is being driven by various institutions and research groups. Some of the important efforts in driving EAF in South Africa are discussed briefly below.

The research in this thesis has been conducted during a changing management context. While the split of MCM into DAFF and DEA occurred prior to the start of this thesis, the implications of this split for EAF in the small pelagic fishery have perpetuated and hindered EAF implementation (Augustyn et al., 2013). Co-operation and co-ordination across departments and even across fisheries within DAFF is limited, making communication and strategic planning for EAF difficult. Institutional changes in DAFF and the lack of human resource capacity and funding for EAF-related research has impeded progress in EAF implementation and lowered priority for engagement with EAF-related projects, such as this one. To better address EAF implementation at the resource management level, Staples (2010) recommended that an EAF management working group be created, but this was never realised. Recently (2014) the EAF-SWG has been dissolved. Recommendations for EAF Task Teams to be set up in each fishery SWG have been made, yet no formal terms of reference have been formulated to realise this as yet, although initial progress has been made in some SWGs (Coetzee, 2014). The

EAF task teams might circumvent the challenge the EAF-SWG had in reaching management by being able to table scientific advice through the SWG to the relevant management working group, but revisions to the general DAFF SWG terms of reference will be needed for this to become effective. The knowledge-based tool has the potential to be a useful aid in establishing an effective strategy for EAF management in the small pelagic fishery through an EAF task team, should it be constituted. This is a potentially valuable tipping point (see Sol et al., 2013) for EAF in South Africa. It will be worthwhile to track whether this new development materialises and if so, how it affects EAF implementation in the next year.

Further progress by DAFF researchers in understanding the spatial shift in the sardine population and evaluating a multiple stock hypothesis for sardine has resulted in improved objectives related to spatially disproportionate fishing. The result of this has also been an attempt to include a spatial component to fishing in management advice for the small pelagic fishery (de Moor et al., 2014). The results of this are still under investigation but have been supported through the International Stock Assessment Review panel (Dunn et al., 2014) and should result in robust indicators for spatialised fishing coming out of the fishery stock assessment process in the future. Including more indicators from TROM modelling may strengthen the knowledge-based tool as it may further improve the links with current management practices. These should be considered in the next iteration of the knowledge-based tool.

The Responsible Fisheries Alliance (RFA), a partnership between WWF South Africa, BirdLife South Africa, and major fishing companies in South Africa, aims to enhance EAF implementation in South Africa, and has made significant progress in this regard. The RFA has, since its inception in 2008, focused its efforts within the South African hake trawl and long-line fisheries but has recently begun to support research related to the small pelagic fishery as well (C. Hagen, BirdLife South Africa, pers. comm.). Further participation in the small pelagic fishery sector is recommended based on the success of the RFAs involvement in the demersal trawl and long-line fisheries and on-going problems within DAFF (Augustyn et al., 2014).

Social science research has contributed to understanding EAF implementation through analysing the efficacy of rights-based approaches in the small pelagic fishery (Hara, 2013, 2014). While the human dimension is not the focus of this thesis, the first prototype tool developed by Paterson et al. (2010) might also need to be updated in light of increased knowledge around human dimensions.

7.4. EAF implementation in other sardine fisheries

Maintaining sustainable fisheries has become a universal goal. The Marine Stewardship Council (www.msc.org) provides the most recognisable benchmark for sustainable fisheries globally. The South African small pelagic fishery has entered into local discussions over MSC certification for sardine and has successfully applied for fish oil and fishmeal certification for anchovy and redeye (IFFO - Marine Ingredients Organisation Global Standard for Responsible Supply, www.iffo.net). To better contextualise the South African sardine fishery in an international arena, I researched the criteria that informs the MSC certification of other sardine fisheries. Four sardine fisheries have received MSC certification to date, namely the Portuguese, Cornwall and South Brittany sardine (*Sardina pilchardus*) fisheries and the Gulf of Mexico sardine (*Sardinops sagax*) fishery, although no assessment reports are available online for the latter. The Cornwall fishery is very small-scale, returning annual catches of less than 1 250 tons by 13 ring net vessels and 12 drift net vessels. The South Brittany sardine fishery operates 20 vessels landing approximately 20 000t a year. The Portuguese sardine fishery is the most similar to South Africa's, acting as a large-scale industrial fishery with almost 100 vessels landing around 78 000t annually of sardine. The performance of fisheries in terms of small-scale and industrial determines the scope and scale of the management of the fishery. A larger fishery will have a bigger impact on the structure and functioning of an ecosystem and would need to be managed differently from a small-scale fishery.

Principle three for MSC certification is of particular interest in placing my research into relevant international context. The MSC's principle three focuses on the effectiveness of the management system. Performance indicators, against which a fishery is scored, include the consultation, roles and responsibilities of stakeholders, and the development of long-term objective indicators and thresholds for fishery management. The knowledge-based tool developed in this thesis can help in addressing these performance indicators through development of long-term management objectives to measure the effectiveness of management in meeting objectives. Many of the objectives addressed in the knowledge-based tool touch on MSC performance indicators in Principles one (sustainability of the exploited stock) and two (maintenance of the ecosystem), for example, the stock status, impact of fishing on retained and bycatch species, and the status of the ecosystem.

In support of the MSC certification proposal for low-trophic-level species, Shannon and Shin (2013) have investigated indicators for small pelagic biomass levels in the southern Benguela ecosystem using trophic-level models, EwE and OSMOSE. These indicators were derived in a comparative systems context (Smith et al., 2011a), and deriving ecological indicators that can be compared to systems elsewhere in the world has its benefits (see for example, Shin and Shannon, 2009 and Shin et al., 2010). Using indicators which can support fisheries seeking MSC certification may help in strengthening the applicability of the knowledge-based tool in strategic planning for an EAF, it should be ascertained whether these indicators could be applied to future iterations of the research presented in this thesis. It should also be considered how these indicators would best be used to complement biomass indicators derived from the recent stock assessments and applied in indicator development in Chapter 3.

Combining indicators through the knowledge-based tool helps to provide information for strategic planning for meeting long-term objectives. This tool may assist in ensuring that decision-making regularly seeks and accepts any new and relevant information, could act as a performance indicator for the process of MSC certification, and benefit effective decision-making through fostering focussed communication with management.

7.5. Limitations and recommendations

Ecological well-being and the sardine fishery

This thesis has focused on the ecological well-being dimension of EAF in the South African sardine fishery. Ecological sustainability is a critical dimension for sustainable fisheries. Should an ecosystem collapse, the fishery in question will fail irrespective of the effectiveness of the human and ability-to-achieve dimensions. However, an EAF requires a holistic approach to effectively address objectives in all three dimensions, and the focus on ecological well-being of the sardine fishery in this thesis has not intended to minimise the importance of these other dimensions. Knowledge-bases for the human well-being and ability-to-achieve dimensions of EAF in the South African small pelagic fishery are under development or in planning (for example, Paterson et al., 2010, Hara, 2013, Augustyn et al., 2014), although social science research has not been prioritised or funded to the same extent as ecological and scientific research in South Africa's marine science programmes (Sowman et al., 2013). Based on the prototype for the human dimension built by Paterson et al. (2010), the present knowledge-based tool can be expanded to incorporate human well-being and ability-to-achieve objectives. I recommend working with stakeholders and experts to develop a suite of objectives that address implementation efficacy in these dimensions and which can be incorporated into future iterations of the knowledge-based tool.

The South African sardine fishery is jointly managed with the anchovy-directed fishery, and the SWG-PEL generates management advice for the small pelagic fishery through an OMP which addresses both sardine and anchovy. Assessing the implementation of EAF on one species of small pelagic fish is therefore limiting, particularly when assessing the impact of fishing on top predators (which will likely also feed on anchovy) and creating synergies with existing management practices. Stakeholders consulted in building the knowledge-based tool recommended that the next iteration of the tool include objectives for the ecological well-being of anchovy, and new developments in collating indicators for the anchovy fishery by Astor (2014) provide the stepping stone to develop the next iteration of the ecological well-being dimension of the knowledge-based tool as a small pelagic tool.

Objectives

The objectives' hierarchy formed the central framework for developing the knowledge-based tool. The objectives were selected during stakeholder meetings in 2007 and 2009. Progress in understanding fishery-ecosystem dynamics and advances in EAF implementation since the objectives were developed suggest that a revised suite of management objectives should be considered. Objectives reflect the priorities, interests and understanding of the stakeholders involved in identifying the issues they address. While it was not observed in this case, the potential to lose stakeholder support and participation as a result of mismatched objectives is a possibility and should be considered in future iterations of this process. I suggest that a possible first step in the next iteration of the knowledge-based tool should be a revision of the underlying management objectives. This is particularly relevant given new understanding and insights into sardine population structure and the likely existence of multiple sardine stocks. Furthermore, new or broader stakeholder groups may have alternative or new objectives that should be included in assessing the implementation efficacy of EAF. I discovered some opposition from stakeholders to the wording or perspective represented by particular objectives in the current suite of objectives. While some objectives were worded differently to address stakeholder concerns, it was deemed more important to complete a full prototype of the knowledge-based tool rather than getting caught up in fine-tuning the ecological objectives. As it is these objectives that inform the indicator selection, however, a revision in objectives with the stakeholders involved in the sardine or small pelagic fishery may improve buy-in and trust around the tool development process.

Refining objectives will require a process similar to those conducted for the ERA and ERA review processes (Nel et al., 2007, Smith and Johnson, 2012). Objective setting necessitates participation by stakeholders from various groups and representing multiple interests. This is time consuming, expensive and demanding.

A risk of running such a process is that it may clash with revisions to the small pelagic ERA process that may be planned. Relying on the same group of stakeholders to participate in workshops with similar goals may result in stakeholder fatigue. Should a revision of the ERA process occur, the results of the knowledge-based tool should be incorporated into both planning and objectives setting. The tool development process has demonstrated buy-in from stakeholders, and the timeline of quantitative evaluation of the ecological objectives through indicators during this process offers more insight into important issues to be addressed at the objectives level. These outcomes will benefit any planned ERA process.

Indicators

Chapter 3 details the process taken to identify ecological indicators and collate the relevant indicator time series, which spanned 22 years, from 1987-2009. 2009 was the last year fully analysed by the relevant experts at the time this section of the research was conducted. I recognise the limitation in contextualising EAF implementation efficacy only until 2009. However, progress in monitoring, collating and analysing the data used in the indicators is delayed in DAFF and DEA through capacity constraints. I decided not to update the indicator time series because the time period displayed in the tool does not significantly affect the findings of this thesis. The period analysed in the tool was significantly long enough to infer the key changes and impacts on the state of the southern Benguela and the pressures the fishery exert on the ecosystem. For the purpose of Chapters 4-6, the tool as it stands was sufficient in engaging discussion among stakeholders. If this tool should be taken up for use by fishery managers within DAFF or by newly identified audiences (see Chapters 5 and 6), then the indicator time series will need to be updated and refined following research progress since this iteration.

A number of objectives were ‘switched off’ in the knowledge-based tool. A lack of long term datasets or monitoring of these issues resulted in these objectives not being linked to indicators. Objectives included that of discard or dumping by the sardine fishery, the bycatch of redeye and juvenile horse mackerel, the disturbance of seabirds by fishing vessels, and the condition of top predators such as seals, sharks, cetaceans, and linefish species which are not dependent on small pelagic species to the same extent as seabirds but whose food requirements nevertheless need to be met. Section 3.4 in Chapter 3 details these objectives and highlights possible new indicators and datasets that may address these objectives in the future.

The 'switched off' objectives indicate areas that require more investigation and understanding for effective EAF implementation. Leaving them in the objectives' hierarchy when communicating with stakeholders opens discussion around priorities and trade-offs for strategic planning for EAF in this fishery.

New and particularly important indicators were highlighted during the parking lot exercise as part of the stakeholder focus group meetings (see Chapter 5). These concerns included providing practical suggestions for new indicators or ways to refine existing indicators to improve the representation of ecological well-being of the sardine fishery in the tool. Addressing these practical considerations should be a priority in future research and can be conducted in parallel with the process of revising management objectives.

The knowledge-based tool

Conceptualising the knowledge-based tool development as an iterative, cyclical process (Figures 1.3 and 6.1) has helped me to address some of the limitations associated with the rapid prototyping approach applied through this thesis. By focusing on developing the tool to prototype despite missing indicators and imperfect datasets, I have been able to avoid bottlenecks in the process as a result of lengthy data-specific discussions between experts. Of course, pushing through to a full working prototype without addressing the concerns of stakeholders has its own disadvantages, including the possibility of stakeholders losing trust in the process and interest in participating, which was a concern through this iteration. To avoid this, the parking lot that listed all stakeholder concerns was useful in keeping focus on tool development while not losing these potentially valuable insights from stakeholders.

Rapid prototyping as developed by Starfield and Jarre (2011) has emphasised working with groups of stakeholders who think in similar ways. While it will be much easier to create a product or model by bringing like-minded stakeholders together to work on a shared problem, the reality is that this is not always possible or even preferable. This is particularly true in this research, where there is potential for the knowledge-based tool to have real-world application in the advisory process for fisheries management. Working with heterogeneous groups of stakeholders with different perspectives, practices and interests will need to rely more on paying attention to the process of building the tool, as differences of opinion and conflicts may occur as a result of stakeholder interaction. This will require careful facilitation and particular focus on building social cohesion. The value of diversity in developing practical and creative solutions should not be overlooked in favour of a product that works on the ground.

The practical steps in building the knowledge-based tool required stakeholder input, which was achieved through a series of meetings with key stakeholders. The aggregation method used in the tool reflects stakeholder preferences. The weighted mean is a simple equation which is easy to understand and calculate. Building the tool in Excel ensures that no special software or expertise is required to run the model or when updating the tool. The knowledge-based tool is simple and transparent. But it is not particularly elegant and the interface is rudimentary. As it was intended that the knowledge-based tool be used by fishery managers, the simplest model using the most easily accessible software was considered appropriate. I wanted to avoid using complicated 'black box' models to ensure that the method was transparent and repeatable. The underlying information is scientifically robust and while elegance may have been lost in the producing visually useful outputs, the knowledge-based tool is meeting the research priorities set out at the start of this thesis.

Stakeholder participation, boundary crossing and social learning

I have included a wide range of stakeholders in developing the knowledge-based tool; however some stakeholders were not included in all steps of tool development. Obviously lacking were representatives of the fishing industry, and more fishery managers. The DAFF fishery managers were contacted to participate in the focus groups in Chapter 5 and they expressed an interest in the meetings and the project, however, most could not commit to a meeting. This may reflect the lower priority for EAF within the DAFF mandate. It was not possible to arrange a focus group meeting with industry during the time available, but industry representatives are formal observers in the SWG-PEL and EAF-SWG and were involved during presentations and feedback meetings around indicator and tool development in the scientific working groups. The stakeholders consulted in this iteration of tool development were predominately from natural science fields or had some training in the natural sciences. As this tool focussed on the ecological well-being dimension of EAF having experts in natural sciences is expected. Should future iterations include the human well-being and governance dimensions of EAF the stakeholder group would need to be to include experts in social sciences and governance fields.

Future iterations of the knowledge-based tool should continue to foster relationships with missing stakeholder groups. Continued focus on increasing involvement by stakeholders involved in stock assessments will help encourage bridge building between the EAF and TROM groups. This will require building trust and social cohesion among stakeholders. Further focus on facilitating social learning during the knowledge-based tool development process should help to bridge this gap.

I conclude this thesis with Chapter 6 reflecting on the success of the knowledge-based tool in functioning as a boundary object and the possible social learning that may have occurred through stakeholder interaction during the tool development process. At the onset of this thesis the focus was strongly on building the knowledge-based tool with stakeholders, with an emphasis on data collection and facilitation of meetings seen as necessary to achieve the goals required to produce a quality product. To this end, I did not focus on empirically testing the outcome of social interactions during the tool development process. As a result, social learning and boundary crossing were not experimentally tested during the tool development process. Further investigation of the boundaries to effective EAF implementation may identify boundaries experienced by stakeholders that are different to those published so far, or expressed in the context of this research.

Despite the lack of empirical evidence for social learning in Chapter 6, I present a strong case for social learning through stakeholder interactions during the tool development process. Drawing on recent literature on successful social learning and developing a suite of key variables and outcome indicators to evaluate progress in social learning in support of EAF implementation should be considered in future research.

7.6. Future iterations

A tool to assess EAF implementation efficacy in the South African small pelagic fishery

Having completed a full prototype of the knowledge-based tool, the next step will be to apply this thesis' findings and reflections in a new round of tool development. This chapter has outlined the key limitations in the thesis alongside recommendations on improving the tool. Developing a knowledge-based tool for the small pelagic fishery that aggregates sardine and anchovy indicators of ecological well-being instead of for the sardine fishery only will improve the tool and more effectively link it to existing management practices. I suggest that future iterations consider a combined tool. Facilitating social learning through stakeholder interaction in developing the tool should be an important focus in any new iteration. The following section provides an outline of how I recommend undertaking the new iteration of building a knowledge-based tool to assess the implementation efficacy of EAF in the South African small pelagic fishery.

Tool development in this thesis has followed an iterative, process approach, as shown in Figure 7.1. This process of linking ecological indicators to existing management objectives, building the knowledge-based tool through an appropriate aggregation method, and communicating the tool outputs and process results among stakeholders are considered key steps in the tool development process. In Figure 7.3 I expand on these process steps for use in the next tool iteration. These steps are displayed as a linear process for ease of presentation in the table, but it should be kept in mind that these steps form part of an iterative process and may include feedback loops and iterations within or between steps. Figure 7.3 outlines key interventions and tasks to be undertaken in each step, including who will participate in each step and indicates what phase in the macro social learning cycle (Wals, et al., 2009; Figure 7.2) may be occurring at each step.

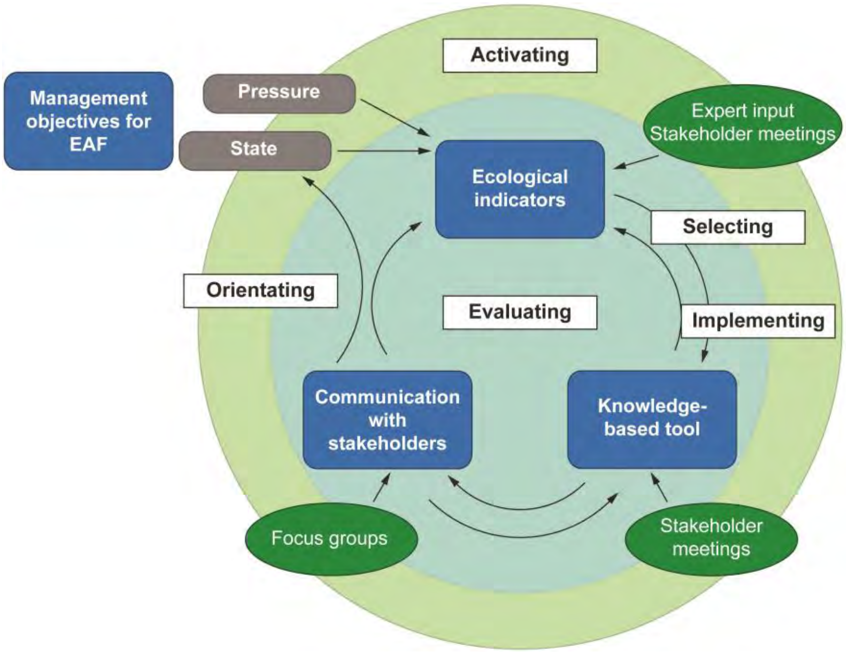
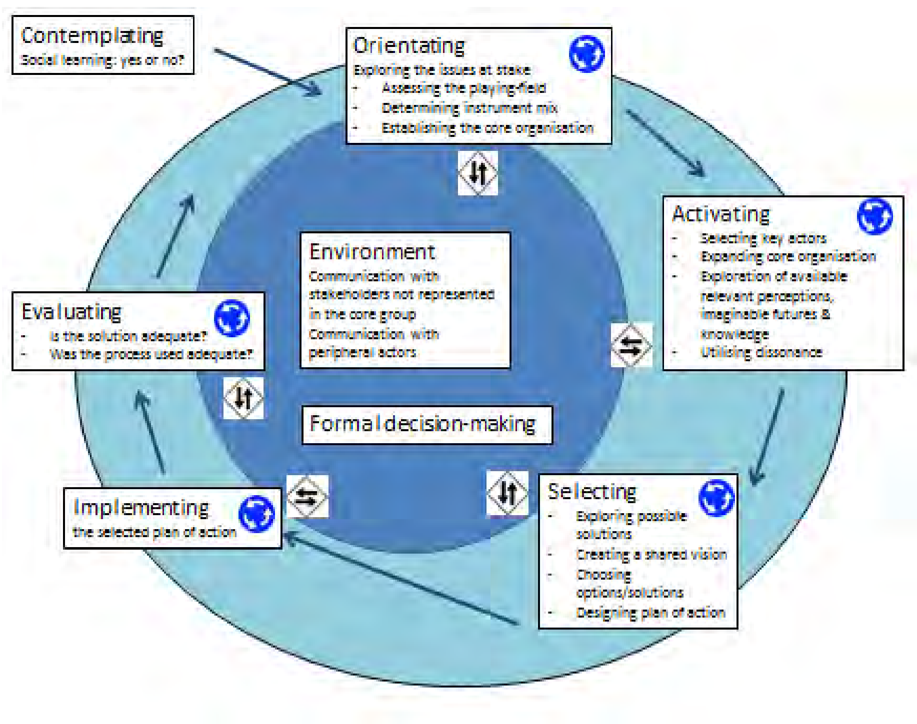


Figure 7.1: The knowledge-based tool development cycle, including social learning phases activated at each step in the process.



"The large circle reflects the macro-learning cycle with a number of different phases in the process. These phases are shown in the figure as separate compartments for the sake of clarity, but it is not always easy to distinguish these in actual practice. … Each phase includes a smaller cycle (roundabout signs) that indicates the importance of reflection in each phase. Each phase also includes a symbol of two-way traffic with the 'environment', the context, which is different in each situation." (Wals et al., 2009)

Figure 7.2: The macro and micro learning cycles in social learning processes (adapted from Wals et al., 2009).

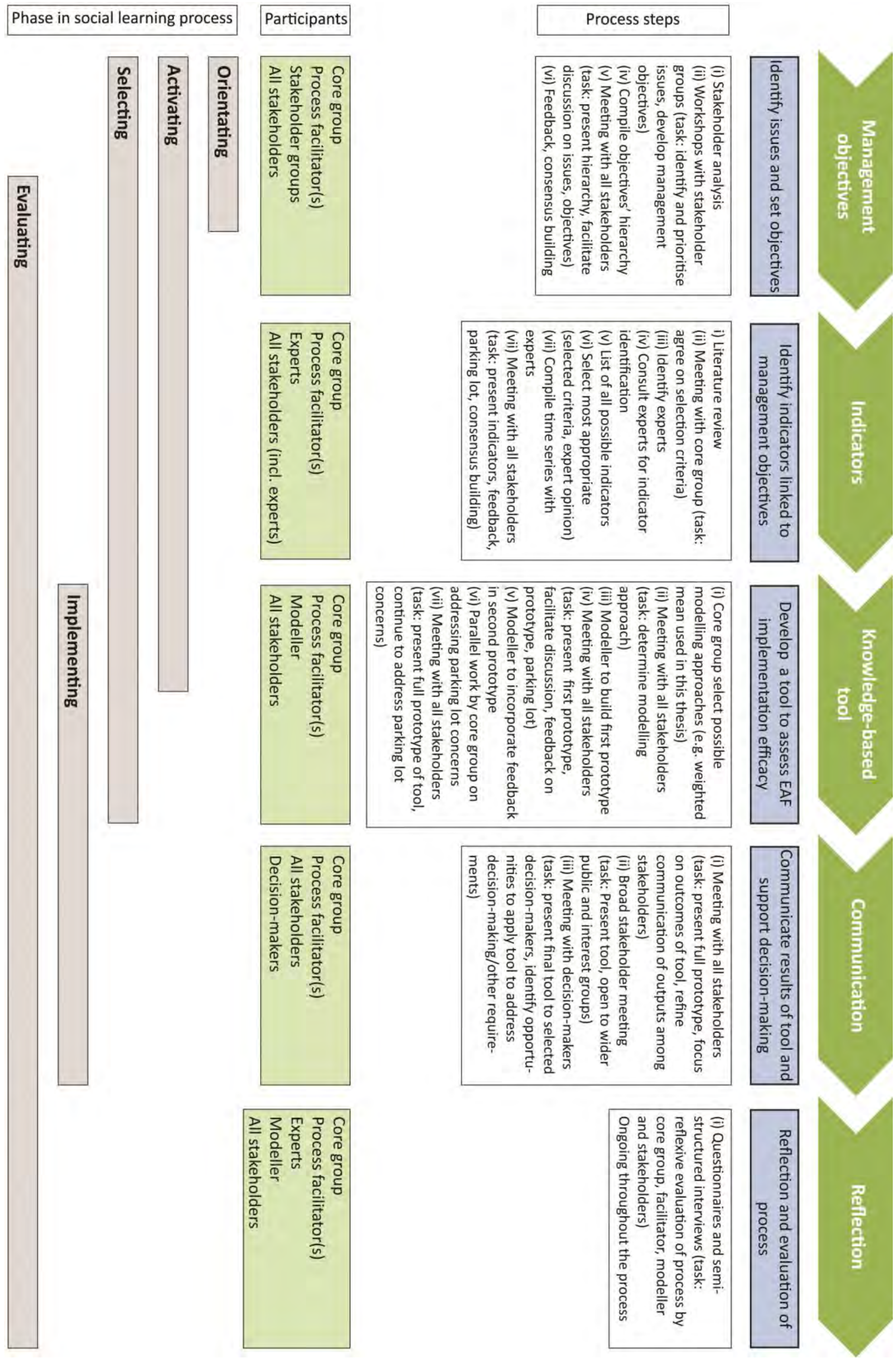


Figure 7.3: Suggested process steps for developing a new iteration of the knowledge-based tool for EAF implementation efficacy in the South African small pelagic fishery. This figure provides the process steps, details of actions and tasks to be addressed during tool development, and suggestions on which stakeholders to include at each step. The social learning phase(s) activated at each step in process are provided at the bottom of the figure.

Before starting the stakeholder process

- Interview the key stakeholders involved in the previous knowledge-based tool development process. These interviews will help to ascertain their views on the success and failure of the process, boundaries to implementing the tool, and other insights that may improve the new iteration.
- Identify all of the potential stakeholders by conducting a thorough stakeholder assessment (for example, Grimble and Wellard, 1997). This analysis will include identifying stakeholder interests and worldviews and identifying potential points of conflict. Anticipating this will help to identify the types of interventions, stakeholder interactions, and facilitation processes that could be applied.
- Set up a core group comprising key actors in the process who share a good understanding of the context of the project and reflect existing interests and perspectives (Wals et al., 2009). A core group for all three dimensions of EAF have already been established through continued stakeholder interactions around developing EAF implementation methodology, facilitated through the SARChI ME&F group. Including social scientists in this group will help in supporting the facilitation and evaluation of social processes.
- Process facilitation is an important consideration at this point. Deciding who will facilitate meetings and ensuring that they have the adequate skills to effectively do so can be done within the core group. Process facilitator(s) must be considered acceptable to all the stakeholders.
- Decide on the ground rules for participation, the best way to address potential conflicts, the protocols for accessing the data, and how to disseminate the outcomes of the process among the stakeholders, decision-makers and the public should be agreed upon early in this process. The core group may outline these approaches, but agreement on these by all stakeholders at the stakeholder meetings must be ensured.

Identify issues and set management objectives

- Conduct a workshop with all identified stakeholders to identify and prioritise issues around EAF implementation in the South African small pelagic fishery, and identify the objectives for each issue.

Paterson et al. (2010) ran focus group meetings to develop objectives for human well-being in the sardine fishery; the methodology applied in their paper is useful to guide this step. The ERA process (Nel et al., 2007, Paterson and Petersen, 2010) has had success in developing process and response indicators for EAF in the small pelagic fishery. These may need revision and new objectives determined to address EAF implementation efficacy. However tapping into this existing process may be a very valuable starting point (Wals et al., 2009). This step will help to make explicit the different stakeholder perspectives and priorities and will require negotiation and discussions around the trade-offs between these priorities. Dissonance among stakeholders is anticipated in this process. With careful facilitation and by making stakeholder perspectives explicit during this step, a shared understanding of the problem situation presented in the objectives' hierarchy may be developed. The convergence of stakeholder perspectives during this step will strengthen subsequent interactions and build trust in the process.

Identify indicators linked to management objectives

- Consult appropriate experts to identify indicators for each objective, and collate relevant data time series for each indicator. Expert consultation will ensure the indicators are based on the best available information and are therefore defensible in a management context.
- Conduct additional stakeholder meetings to ensure the objectives' and indicator suite are considered appropriate. Spending time creating a favourable environment where stakeholders concerns are addressed and trust and cohesion among the group is facilitated will support tool development at this stage.

Building the knowledge-based tool

- Conduct stakeholder meetings to decide on the technical steps in building the knowledge-based tool. The core group should determine possible methods for aggregating the objectives and indicators (for example, Jarre et al. (2008) compared rule-based and 'Fuzzy AND', while this thesis used a weighted mean). Consultation with Multi-Criteria Decision Analysis experts in the UCT Department of Statistics in developing methodologies for building the knowledge-based tool may help in developing new approaches and software to apply the tool.
- Select an appropriate aggregation method based on stakeholder input. The method chosen will determine what information needs to be collected. For example, should a weighted mean equation be used, expert-determined threshold values for each indicator will need to be determined and weights selected for the objectives and the indicators. Additional meetings with experts and stakeholders may be required to do this. I have included the participation of a modeller in this step. The modeller can be a member of the core group, an expert external to the process, or the process facilitator. The role of this person is to rapidly build a prototype of the tool based on suggestions by the stakeholders. This can be done during the stakeholder meeting or between stakeholder meetings. This is useful in rapid prototyping and will be an effective way of quickly building the tool with the adequate expertise to do so.
- The parking lot worked well to create space to address stakeholder's concerns or issues not included in the tool development process. Having members of the core group address the parking lot concerns with relevant stakeholders in parallel to the main process will ensure these concerns are not lost along the way, are clearly documented, and may help in ensuring continued engagement with stakeholders through the process.

Communicate results of tool and support decision-making

- Refining the presentation and the visualisation of the tool outputs among stakeholders should include a consideration of the end users and the potential fora for application of the tool. Meetings with decision-makers will help in making the tool useful. These stakeholders should have been included in the development process, but refining and improving the tool where possible may be necessary to ensure that it is useful in addressing decision-making or other requirements.

Reflection and evaluation of the process

- Reflection and evaluation of the process and the tool outputs is an important step in this process and should be built into each step. Qualitative assessments of the process by the core group and the process facilitator should be done throughout the process. These assessments should be flexible, but may include meeting recordings, transcripts, field notes, and interviews. Questionnaires and semi-structured interviews offer the opportunity to quantify the stakeholder's reflections on the process steps. These provide the space to build reflexivity into the process by considering the outcomes at each step of the process. They will also give monitoring outputs on the soft results of social learning through assessing what learning has occurred and how social cohesion, personal relationships, and stakeholder perspectives may have changed through these steps. Results of these should be reported on in stakeholder meetings.

Social learning

- A strong focus should be placed on enhancing the social learning process in the next prototype of the knowledge-based tool. Social learning is characterised by the collective action and reflection that occurs within a group of stakeholders working together towards a common goal. The knowledge-based tool development process offers opportunity for more effective facilitation of social learning among stakeholders. Wals et al. (2009) consider six phases or learning cycles in a social learning process (Figure 7.2). These provide a useful framework in which to orientate social learning through tool development. These phases form macro- and micro-learning cycles. While characterised by distinct steps, the social learning phases are not clearly defined and it can be difficult to determine a start and end point between them. Micro learning cycles occur within each phase and as result each process step may include more than one of the social learning phases. Figure 7.3 demonstrates which social learning phase occurs in each step of the tool development process.

- *Orientating*

This phase helps set the scene for the social learning process. This is when the context in which learning may occur is assessed, the methodologies are determined, and the core group is formed. Effective process facilitation will help to cultivate a commitment from stakeholders to remain involved. It is important to address divergence and conflict within the core group at this stage.

- *Activating*

This phase entails selecting the relevant stakeholders, expanding the core group, and exploring the various perceptions within the stakeholder group. The activating phase is important in dealing with dissonance within the group and finding ways to utilise this divergence to support social learning (Wals et al., 2009). The convergence of stakeholder perceptions and practices is anticipated in this phase, but is not guaranteed.

- *Selecting*

Selecting an appropriate solution to the problem situation. Once again, it is important to deal with any conflicts and address trade-offs at this stage.

- *Implementing the selected plan of action*

It is during this phase the achieved progress is made visible through reporting and feedback. This includes the hard results, which in the context of the tool development process include the objectives' hierarchy, indicator suite and progress in tool development, as well as the softer results such as improved personal relationships, co-operation and involvement of stakeholders.

- *Evaluating*

Monitoring and evaluation is an important step in social learning and requires reflection on the process. Asking whether the selected solution and plan of implementation has been adequate is a vital consideration. This phase helps to make visible any changes that may have occurred during the social learning process.

7.7. Conclusion

This concluding chapter has recapped the iterative flow of this thesis and has put the findings into the general context of EAF implementation in the South Africa. It has provided a detailed suggestion on building a new iteration of the knowledge-based tool to assess the efficacy of EAF implementation in the small pelagic fishery incorporating more focused attention on the social processes occurring during tool development through facilitated social learning processes. It has done this in a transparent, reproducible and scientifically defensible manner. I submit that it is the combined focus on tool development and social processes that will steer us in the right direction towards effectively implementing an EAF in the small pelagic fishery and could be a useful model for other fisheries in southern Africa.

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Appendix

Appendix 1

List of possible indicators for objectives of ecological well-being in the South African sardine fishery identified by experts.

<table>
<tr><th>Broad objective</th><th>Management objective</th><th>Indicator</th><th>Experts consulted and professional affiliation</th><th>Data source(s)</th></tr>
<tr><td colspan="3">Pressures exerted by the sardine fishery</td><td></td><td></td></tr>
<tr><td rowspan="3">Optimise sardine mortality</td><td>Optimise exploitation rate</td><td>Exploitation rate</td><td>Tracey Fairweather (DAFF)
Deon Durholtz (DAFF)</td><td>Fairweather et al. (2006a)</td></tr>
<tr><td>Minimise bycatch of juvenile sardine</td><td>Bycatch of juvenile sardine</td><td>Janet Coetzee (DAFF)</td><td>Coetzee et al. (2008a)
Van der Lingen et al. (2006)
Coetzee (2006)
Coetzee and Merkle (2007)</td></tr>
<tr><td>Minimise discard in the sardine-directed fishery</td><td>Extent of dumping in the sardine fishery (GLM)</td><td>Carl van der Lingen (DAFF)
Jan van der Westhuizen (DAFF)</td><td>Sobhlaba et al. (2014)</td></tr>
<tr><td rowspan="2">Eliminate spatially disproportionate fishing</td><td>Proportion of catch west of Cape Agulhas reflects the distribution of sardine in the population</td><td>Proportion of sardine caught west of Cape Agulhas</td><td rowspan="2">Carl van der Lingen (DAFF)
Jan van der Westhuizen (DAFF)
Janet Coetzee (DAFF)</td><td>Coetzee et al. (2008b)</td></tr>
<tr><td>Catch of large sardine in catch west of Cape Agulhas reflects the proportion of large sardine in the population west of Cape Agulhas</td><td>Ratio of large sardine in the sardine-directed catch west of Cape Agulhas</td><td>Coetzee (2006)
Coetzee and Merkle (2007)
Van der Lingen et al. (2006)</td></tr>
<tr><td rowspan="2">Minimise bycatch in the sardine fishery</td><td>Minimise bycatch of redeye</td><td>None identified</td><td rowspan="2">Carl van der Lingen (DAFF)</td><td></td></tr>
<tr><td>Minimise bycatch of juvenile mackerel</td><td>None identified</td><td></td></tr>
</table>

Appendix 1 continued

Broad objective	Management objective	Indicator	Experts consulted and professional affiliation	Data source(s)
State of the southern Benguela ecosystem				
Minimise disturbance of seabirds by the sardine fishery	Few fishing vessels passing in the vicinity of colonies of seabirds with conservation status	None identified	Astrid Jarre (MA-RE, UCT)	Weller et al. (2014) Sherley et al. (submitted)
Maintain target species in a highly productive state	Maintain spawner stock biomass (SSB) above a level where abundance has historically been able to increase in the presence of fishing	Survey-derived SSB	Janet Coetzee (DAFF)	
		1^{+} SSB	Janet Coetzee (DAFF) Caryn de Moor (MARAM, UCT)	de Moor and Butterworth (2008)
	Sardine in good condition	Condition factor	Carl van der Lingen (DAFF)	van der Lingen et al. (2006)
		Sardine relative weight	Hilkka Ndjaula (MA-RE, UCT)	Ndjaula et al. (2013)
Maintain a forage base for dependent seabirds	African penguin populations on western islands in good nutritional condition	African penguin health index	Rob Crawford (DEA) Les Underhill (ADU, UCT)	
		Number of breeding pairs of African Penguins on western islands	Rob Crawford (DEA) Les Underhill (ADU, UCT) Lorien Pichegru (ADU, UCT) Lauren Waller (ADU, UCT)	Crawford et al. (2011)
		Breeding success (chicks/pair)		
		Chick condition		
		Number of adults and immature penguins in moult		
	African penguin populations on eastern islands in good nutritional condition	Number of breeding pairs of African Penguins on eastern islands	Rob Crawford (DEA) Les Underhill (ADU, UCT) Lorien Pichegru (ADU, UCT) Lauren Waller (ADU, UCT)	Crawford et al. (2011)
		Breeding success (chicks/pair)		
	Healthy seabird populations in	Number of breeding pairs of Cape	Rob Crawford (DEA)	Crawford et al. (2007b)

Broad objective	Management objective	Indicator	Experts consulted and professional affiliation	Data source(s)
	general	cormorants	Les Underhill (ADU, UCT)	
		Number of breeding pairs of Swift terns	Rob Crawford (DEA) Les Underhill (ADU, UCT)	Crawford (2009)
		Number of breeding pairs of Cape gannets (breeding area - ha)	Rob Crawford (DEA) Les Underhill (ADU, UCT)	Crawford et al. (2007b)
Maintain forage base for other dependent predators	Snoek in good condition	Snoek diet	Larry Hutchings (DEA)	McQueen and Griffiths (2004) Griffiths et al. (2002)
	Other linefish in good condition		Colin Attwood (MA-RE, UCT) Sven Kerwath (DEA)	Smale (1992) Winker (2013)
	Sharks in good condition	None identified	Charlene da Silva (DAFF)	
	Cetaceans in good condition	Dusky dolphin diet	Stephanie Plon (Bayworld) Peter Best (Bayworld) Shan Ambrose (Rhodes University)	Ambrose et al. (2013)
	Seals in good condition	Seal pup condition	Steve Kirkman (DEA) Herman OOsthuizen (DEA) Mdudusi Smseakamela (DEA)	Kirkman (2010)
		Seal pup weight		
		Seal pup numbers		
		Seal diet		

Appendix 2

Stakeholder’s weight selection for objectives and indicators for ecological well-being of EAF in the South African sardine fishery.

Knowledge based tool to assess the implementation of an EAF in the South African sardine fishery

Choice of weights for combining indicators and objectives under weighted mean calculation

The weights selected at a meeting held in Pringle Bay are presented for reference. The objectives hierarchy is presented in the first column. The broad objectives are shaded dark grey and in bold. Specific objectives are shaded light grey and indicators are not shaded.

NAME: Newia	**Pringle Bay weights**	**Your selected weights**	**Any reasons/ explanations for your choice in weights**
Pressure	**70**	50	Manage the pressure
Optimise sardine mortality	30	50	reduce mortality
Sardine exploitation rate	60	50	
Bycatch of juvenile sardine	40	50	
Eliminate spatially disproportionate fishing	70	70	This allows at least allocating catches on areas/
Proportion of catch of sardine west of Cape Agulhas	50	40	most predator are in west coast will be good to leave more for them
Ratio of catch large sardine in population west of Cape Agulhas	50	60	low catch in west coast will allow more food for predator
State	**30**		
Maintain target species in highly productive state	30	40	low impact on the removal of other sp
1+ Spawner stock biomass	70	60	
Sardine relative weight	30	40	
Maintain forage base for dependent seabirds	70	70	important to take consideration of seabird spatial management!
Penguin health index of penguins found on west islands	35	40	limited foraging range low chicks conditions
Penguin population on the eastern islands	20	20	Much better condition longer foraging range
Cape cormorant population in Western Cape	15	10	~~not~~ NB to ~~cons~~ maintain pop at ~~~~ its state
Cape gannets, area of occupied nesting sites in Western Cape	15	15	~~can~~ need ~~this~~ sardines during breeding but not much affected while not.
Swift tern population in Western Cape	15	15	need to maintain breeding colony

Knowledge based tool to assess the implementation of an EAF in the South African sardine fishery

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NAME: CARL	Pringle Bay weights	Your selected weights	Any reasons/ explanations for your choice in weights
Pressure	70	70	
Optimise sardine mortality	30	40	increased pop size = range expansion - likely improve spatially
Sardine exploitation rate	60	50	objective of cmt / dep fishing
Bycatch of juvenile sardine	40	50	sardine juvenile landings likely underestimate (dumping)
Eliminate spatially disproportionate fishing	70	60	Likely/possible implementation of spatially-explicit mgt could alleviate such
Proportion of catch of sardine west of Cape Agulhas	50	70	meaningful data, sold indicator
Ratio of catch large sardine in population west of Cape Agulhas	50	30	Variable, fluctuating, not such a good indicator
State	30	30	
Maintain target species in highly productive state	30	20	objective of cmt
1+ Spawner stock biomass	70	60	Still important but less so
Sardine relative weight	30	40	Fat, fecund, fish impt - also integrate environment too
Maintain forage base for dependent seabirds	70	80	Emphasize ecosystem effects
Penguin health index of penguins found on west islands	35	40	western pop^n under more serious threat than eastern
Penguin population on the eastern islands	20	15	pops
Cape cormorant population in Western Cape	15	10 ~~15~~	
Cape gannets, area of occupied nesting sites in Western Cape	15	25 ~~20~~	Gannets more threatened than cormorants or terns
Swift tern population in Western Cape	15	10	

Knowledge based tool to assess the implementation of an EAF in the South African sardine fishery

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"interesting to run"

NAME: Carl #2	Pringle Bay weights	Your selected weights	Any reasons/ explanations for your choice in weights
Pressure	**70**	90	Mgt can affect this directly
Optimise sardine mortality	30	70	
Sardine exploitation rate	60	50	
Bycatch of juvenile sardine	40	50	
Eliminate spatially disproportionate fishing	70	30	
Proportion of catch of sardine west of Cape Agulhas	50	70	
Ratio of catch large sardine in population west of Cape Agulhas	50	30	
State	**30**	10	Mgt less likely to affect this directly
Maintain target species in highly productive state	30	20	
1+ Spawner stock biomass	70	50	
Sardine relative weight	30	50	
Maintain forage base for dependent seabirds	70	80	
Penguin health index of penguins found on west islands	35	40	
Penguin population on the eastern islands	20	10	
Cape cormorant population in Western Cape	15	10	
Cape gannets, area of occupied nesting sites in Western Cape	15	30	
Swift tern population in Western Cape	15	10	

Knowledge based tool to assess the implementation of an EAF in the South African sardine fishery

Choice of weights for combining indicators and objectives under weighted mean calculation

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NAME: CARRYH	Pringle Bay weights	Your selected weights	Any reasons/ explanations for your choice in weights
Pressure	**70**	70	
Optimise sardine mortality	30	30	
Sardine exploitation rate	60	60	
Bycatch of juvenile sardine	40	50	
Eliminate spatially disproportionate fishing	70	60	much sardine on S coast at ob range of vessels - high proportion of the E of Agulhas
Proportion of catch of sardine west of Cape Agulhas	50	50	
Ratio of catch large sardine in population west of Cape Agulhas	50	60	
State	**30**	30	
Maintain target species in highly productive state	30	40	
1+ Spawner stock biomass	70	70	
Sardine relative weight	30	30	
Maintain forage base for dependent seabirds	70	60	other predators probably as important as hake, tuna, Linefish.
Penguin health index of penguins found on west islands	35	35	
Penguin population on the eastern islands	20	20	
Cape cormorant population in Western Cape	15	15	don't know current status
Cape gannets, area of occupied nesting sites in Western Cape	15	15	"
Swift tern population in Western Cape	15	15	"

Knowledge based tool to assess the implementation of an EAF in the South African sardine fishery

Choice of weights for combining indicators and objectives under weighted mean calculation

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NAME: Rob C.	Pringle Bay weights	Your selected weights	Any reasons/ explanations for your choice in weights
Pressure	**70**	✓	
Optimise sardine mortality	~~30~~	25	
Sardine exploitation rate	60	✓	
Bycatch of juvenile sardine	40	✓	
Eliminate spatially disproportionate fishing	~~70~~	75	Disproportionate fishing may have severe impacts at seabird colonies
Proportion of catch of sardine west of Cape Agulhas	50	75	It is the availability of large sardines to seabirds on the west coast that is most important
Ratio of catch of large sardine in population west of Cape Agulhas	50	25	
State	**30**	✓	
Maintain target species in highly productive state	30	✓	
1+ Spawner stock biomass	70	✓	
Sardine relative weight	30	✓	
Maintain forage base for dependent seabirds	70	✓	
Penguin health index of penguins found on west islands	35	✓	
Penguin population on the eastern islands	20	✓	
Cape cormorant population in Western Cape	15	✓	
Cape gannets, area of occupied nesting sites in Western Cape	15	✓	
Swift tern population in Western Cape	15	✓	

Ashwd

Knowledge based tool to assess the implementation of an EAF in the South African sardine fishery

Choice of weights for combining indicators and objectives under weighted mean calculation

The weights selected at a meeting held in Pringle Bay are presented for reference. The objectives hierarchy is presented in the first column. The broad objectives are shaded dark grey and in bold. Specific objectives are shaded light grey and indicators are not shaded.

NAME: ______________	Pringle Bay weights	Your selected weights	Any reasons/ explanations for your choice in weights
Pressure	**70**		
Optimise sardine mortality	30		
Sardine exploitation rate	60	fine	
Bycatch of juvenile sardine	40		
Eliminate spatially disproportionate fishing	70		
Proportion of catch of sardine west of Cape Agulhas	50	30-20	
Ratio of catch large sardine in population west of Cape Agulhas	50	70-80	yes more variable in time series but still important ~ re-establishing spawning pop on west coast.
State	**30**		
Maintain target species in highly productive state	30		
1+ Spawner stock biomass	70	fine	
Sardine relative weight	30		
Maintain forage base for dependent seabirds	70		
Penguin health index of penguins found on west islands	35		
Penguin population on the eastern islands	20	fine	
Cape cormorant population in Western Cape	15		
Cape gannets, area of occupied nesting sites in Western Cape	15		
Swift tern population in Western Cape	15		

Knowledge based tool to assess the implementation of an EAF in the South African sardine fishery

Choice of weights for combining indicators and objectives under weighted mean calculation

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NAME: Herman	Pringle Bay weights	Your selected weights	Any reasons/ explanations for your choice in weights
Pressure	**70**	70	
Optimise sardine mortality	30	30	
Sardine exploitation rate	60	80 ↑	As fishery is not ~~spatial or~~ temporal managed - Could thus have local depletions.
Bycatch of juvenile sardine	40	40	
Eliminate spatially disproportionate fishing	70	80 ↑	This is important as it could mean local depletion of sardines in small but important area to predators
Proportion of catch of sardine west of Cape Agulhas	50	50	
Ratio of catch large sardine in population west of Cape Agulhas	50	50	
State	**30**	30	
Maintain target species in highly productive state	30	30	Leave the same as my knowledge on differences between 3 ~~are~~ is limited
1+ Spawner stock biomass	70	70	
Sardine relative weight	30	30	
Maintain forage base for dependent seabirds	70	80 ↑	Even higher as 80% if possible as the conservation status of seabirds and in particular penguins are of high concern
Penguin health index of penguins found on west islands	35	80 ↑	"
Penguin population on the eastern islands	20	80 ↑	"
Cape cormorant population in Western Cape	15	double-40 ↑	I am not sure why so low if the aim is to maintain healthy populations. even if their status is not currently of the same concern as penguins.
Cape gannets, area of occupied nesting sites in Western Cape	15	double-40 ↑	
Swift tern population in Western Cape	15	double-40 ↑	

Knowledge based tool to assess the implementation of an EAF in the South African sardine fishery

Choice of weights for combining indicators and objectives under weighted mean calculation

The weights selected at a meeting held in Pringle Bay are presented for reference. The objectives hierarchy is presented in the first column. The broad objectives are shaded dark grey and in bold. Specific objectives are shaded light grey and indicators are not shaded.

NAME: ____________	Pringle Bay weights	* Your selected weights	Any reasons/ explanations for your choice in weights
Pressure	**70**	70	
Optimise sardine mortality	30	30	
Sardine exploitation rate	60	60	
Bycatch of juvenile sardine	40	40	
Eliminate spatially disproportionate fishing	70	70	
Proportion of catch of sardine west of Cape Agulhas	50	50	
Ratio of catch large sardine in population west of Cape Agulhas	50	50	
State	**30**	30	
Maintain target species in highly productive state	30	30	
1+ Spawner stock biomass	70	70	
Sardine relative weight	30	30	
Maintain forage base for dependent seabirds	70	70	
Penguin health index of penguins found on west islands	35	35	
Penguin population on the eastern islands	20	20	
Cape cormorant population in Western Cape	15	15	
Cape gannets, area of occupied nesting sites in Western Cape	15	15	
Swift tern population in Western Cape	15	15	

* Dont have enough background to justify any change to these values.

Knowledge based tool to assess the implementation of an EAF in the South African sardine fishery

Choice of weights for combining indicators and objectives under weighted mean calculation

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NAME: Steve	**Pringle Bay weights**	**Your selected weights**	**Any reasons/ explanations for your choice in weights**
Pressure	~~[illegible]~~ ~~70~~	60	
Optimise sardine mortality	30	50	
Sardine exploitation rate	60		
Bycatch of juvenile sardine	40		
Eliminate spatially disproportionate fishing	70	50	feel that the use of E/W of Cape Agulhas is too simplistic.
Proportion of catch of sardine west of Cape Agulhas	50	35	Too late to change now but feel that its importance should
Ratio of catch large sardine in population west of Cape Agulhas	50	35	possibly be reduced
State	~~30~~	40	As above, as perhaps there is too much emphasis on the spatial thing
Maintain target species in highly productive state	30		
1+ Spawner stock biomass	70		
Sardine relative weight	30		
Maintain forage base for dependent seabirds	70		
Penguin health index of penguins found on west islands	35		
Penguin population on the eastern islands	20		
Cape cormorant population in Western Cape	15		
Cape gannets, area of occupied nesting sites in Western Cape	15		
Swift tern population in Western Cape	15		

Appendix 3

Copy of the email invitation sent to selected stakeholders to participate in a focus group meeting.

Dear, xxx

My name is Emily McGregor. I am a student in the UCT Zoology Department, working towards my PhD under the supervision of A/Professor Astrid Jarre (UCT) and Dr Carl van der Lingen (Fisheries Branch, DAFF). We have identified you as a key stakeholder in the management of the South African sardine fishery and would like to invite you to participate in a focus group meeting to provide input to the visualisation and communication of the outputs knowledge-based tool I have developed as part of my research.

My PhD thesis aims to evaluate the implementation efficacy of an Ecosystems Approach to Fisheries management (EAF) in the South African sardine fishery. The project is divided into three parts, namely: (i) identifying indicators related to the ecological well-being of the sardine fishery, (ii) developing a knowledge-based tool to combine these indicators to present an evaluation of the effectiveness of EAF implementation in this fishery and (iii) explore ways of communicating the outputs of this tool to key stakeholders. These phases are interlinked and iterations at each step feed back into the other parts of the project.

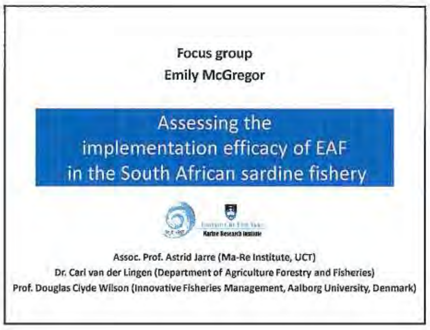
We recognise that stakeholders may have different understandings of the input data, the outputs and ways of presenting these. An important part of my research is, therefore, to obtain input and feedback from sardine fishery stakeholders throughout the process of developing the knowledge-based tool. At this stage in my PhD I would like to get **feedback on the presentation of the knowledge-based tool**, in particular the visualisation of the tool outputs. I plan to do this by conducting a series of focus group with key stakeholders. The goal of these focus groups will be to present my current progress and facilitate a discussion between stakeholders on possible ways of presenting the outputs of the knowledge-based tool with the
These meetings will be held at the DAFF offices in Cape Town and should last no longer than two hours. Please indicate by replying directly to this email, whether you are willing to participate and would be able to attend one of these meetings.

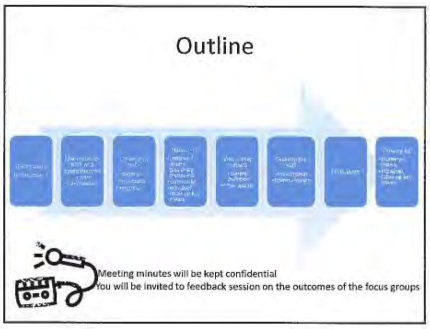
I have a few dates in mind for the meeting; please could you indicate in your email which day would be best for you. From your reply we will find a date that is most appropriate for the majority of participants.

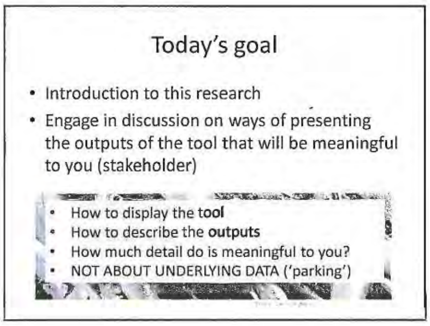
Thank you and kind regards,
Emily

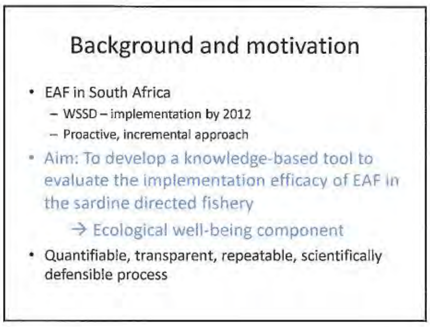
Appendix 4

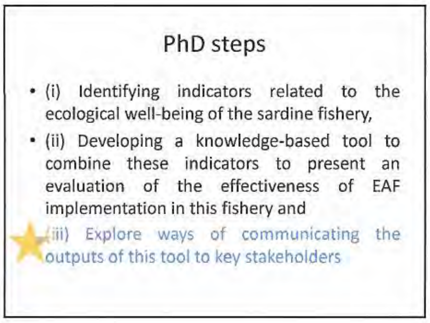
PowerPoint presentation given at the four focus group meetings – page 1.

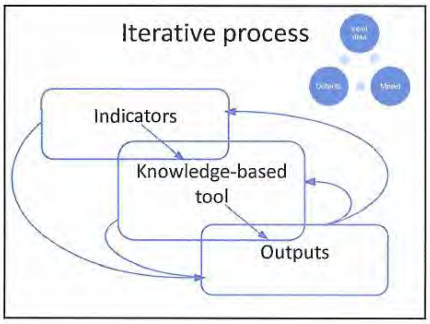






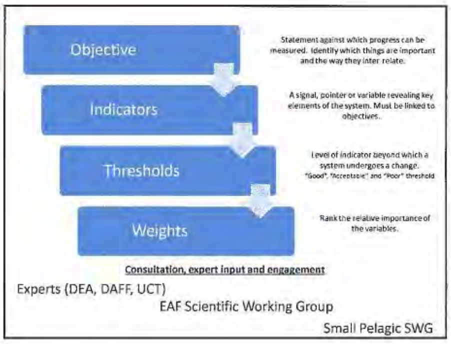


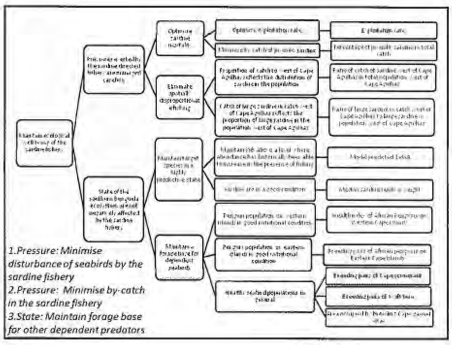


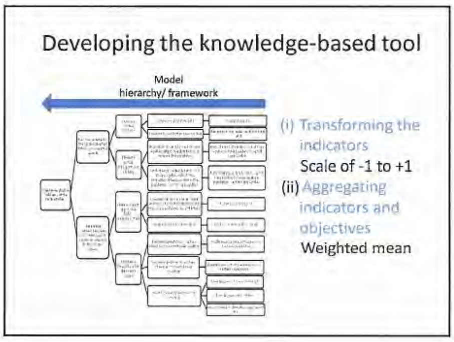


1

PowerPoint presentation given at the four focus group meetings – page 2.

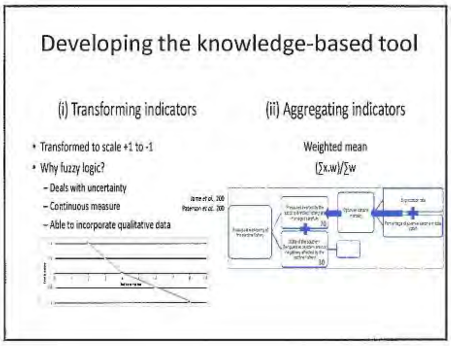


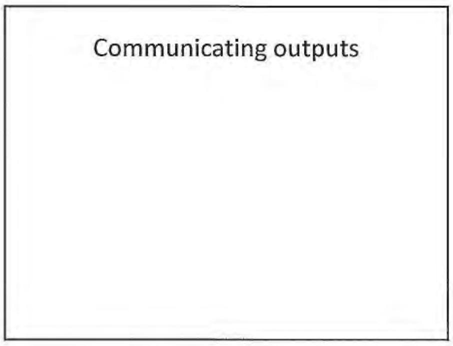


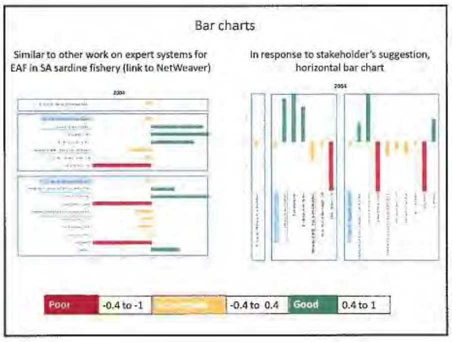


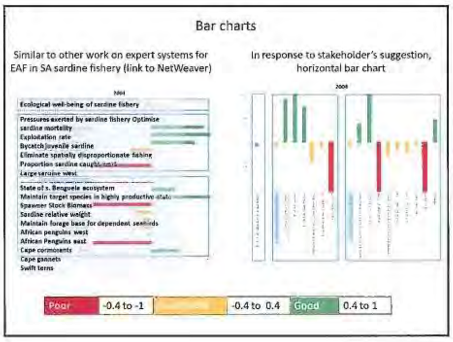
2

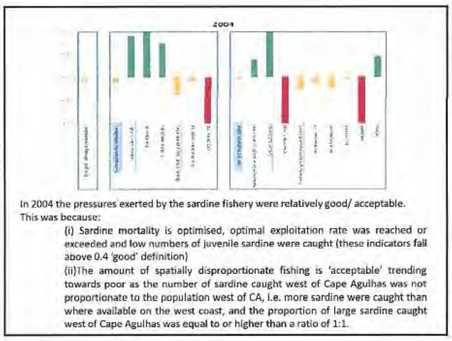
PowerPoint presentation given at the four focus group meetings – page 3.

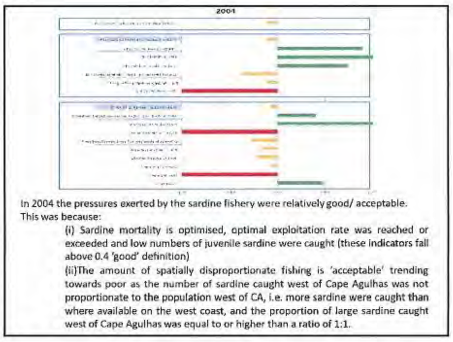








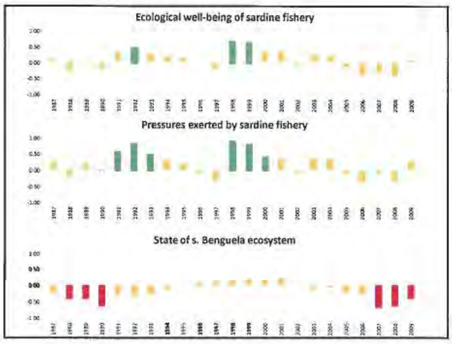




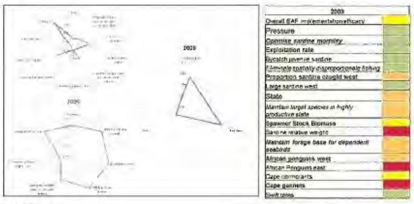
3

PowerPoint presentation given at the four focus group meetings – page 4.

Snapshot in time, or trend over time?



Alternatives



Kite Diagram

(Garcia *et al*., 2000)

'Robot' or traffic light

"Parking lot"

Some issues and comments about inputs

Anything you want to raise here?

Follow up after meeting

THANK YOU

Any further questions or suggestions

4